XI International Symposium

Radiation from Relativistic Electrons in Periodic Structures

September 6-11

Saint Petersburg, Russia

XI International Symposium

"RREPS-15"

Radiation from Relativistic Electrons in Periodic Structures

6-11 September 2015, Saint Petersburg, Russia

Organized by the Saint Petersburg State University, National Research Nuclear University "MEPhI" and Tomsk Polytechnic University

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Schedule (preliminary)

Day	Morning	Afternoon	Evening
September 6 Sunday		Registration	Welcome Party
September 7 Monday	Registration, Opening and Oral Session	Oral Session	Poster session
September 8 Tuesday	Oral Session	Oral Session	Poster session
September 9 Wednesday	Oral Session	Symposium Excursion	Symposium Excursion
September 10 Thursday	Oral Session		Symposium Dinner
September 11 Friday	Oral Session	Closing	Departure
September 12 Saturday	Departure	Departure	

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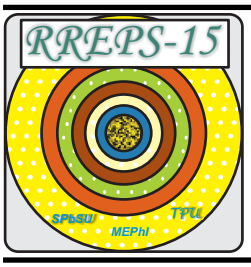
The Summary

Contents



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Section 1

General Aspects of Physical Phenomena and Processes Associated with Electromagnetic Radiation: Day 1

For Notes

TWISTED PHOTONS AND ELECTRONS AS A NEW TOOL IN PHYSICS OF ATOMS, NUCLEI AND ELEMENTARY PARTICLES

Valeriy Serbo[1]

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In modern optics there are well known states of the laser beam whose photons have a nonzero value of the orbital angular momentum projection on the beam propagation axis. Very recently new experiments had been performed in which the twisted photons with the energy of two orders of magnitude larger and smaller had been produced. Moreover, several groups have reported successful creation of twisted electrons and their remarkable focusing to a focal spot of less than 0.12 nm in diameter.

In my talk I review unusual properties of several atomic processes with twisted photons and electrons (new selection rules, unusual angular distribution and polarization of the final particles) which had been discuss in our recent papers.

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DIELECTRIC BASED THZ RADIATION AND ACCELERATION: PRESENT STATUS AND PERSPECTIVES

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Cherenkov radiation from particle bunches is of considerable importance in many areas of fundamental and applied physics. Recent experiments has demonstrated that proper adjustment of the electron beam parameters to the guiding structure geometry scaled from sub millimeter dielectric waveguides to nanoscale periodic structures allows to generate radiation, ranging from low terahertz to visible light. Using Cherenkov radiation generated by a high current bunch passing a dielectric wake-field accelerator (DWA) may provide a significant cost saving and reduction of the linear collider or FEL facility size. Femtosecond or picosecond electron bunches are used for high power THz generation for particle acceleration as well. With this talk, we present our recent developments on (1) wakefields generation by using dielectric based structures and introducing an energy modulation that allows high power THz radiation in the range 0.5 - 1 THz (2) THz passive energy chirp correction (3) a concept for a multi-beamline FEL driven by high repetition rate dielectric based wakefield accelerators.

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GENERATION OF CONCENTRATED RADIATION OF PARTICLE BUNCHES USING DIELECTRIC TARGETS AND WIRE STRUCTURES

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We present analytical and numerical investigation of nontraditional methods for obtaining concentrated radiation from particle bunches. The objects considered here are simultaneously "generators" and "concentrators" of radiation. First, we consider dielectric objects which can concentrate radiation near some line or some point. The form of the targets is determined using the ray optics, but the field is calculated using the aperture integration method. Typical spatial distributions of the field outside the targets are presented. They demonstrate large amplification of the field in the focus neighborhood in comparison with the field on the surface of the target.

Further we describe radiation in 3-D wire metamaterial which is a periodic structure of long metal conductors with small spacing. This structure is described by an effective permittivity tensor. The moving charged particle bunch generates non-divergent Cherenkov radiation in the structure at any velocity. We demonstrate typical images of wave field from different bunches and show that these images can be used for the bunch diagnostics. We also consider the 2-D wire structure (planar grid) with small period (using the averaged boundary conditions method). The most interesting part of the radiation is the surface wave which can be useful for the bunch diagnostics.

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RADIATION OF A CHARGED PARTICLE BUNCH MOVING ALONG THE EDGE OF SEMI-INFINITE PLANAR PERIODIC WIRE STRUCTURE

Viktor Vorobev[1]***, Andrey Tyukhtin, Sergey Galyamin***

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Three-dimensional and planar periodic structures made of thin conductors and having small period can be used for non-destructive diagnostics of charged particle bunches. Earlier we analysed radiation from bunches moving in volume wire metamaterial and along the boundary of such material. We also studied radiation of bunches moving in the presence of infinite planar structures. Now we consider a semi-infinite planar periodic structure made of thin parallel wires, which are placed orthogonally to the structure edge. We assume that particle bunch with negligible thickness and finite length moves parallel to the edge. The structure period is much less than the wavelength under consideration and the thickness of conductors is much less than the period. The electromagnetic influence of such grid is described by the known averaged boundary conditions. The radiation is represented by a surface wave with specific properties. This wave propagates along wires with speed of light in vacuum (if losses are negligible) without change of shape. Its structure allows determining the size of bunch. Properties of this surface wave are similar to the properties of volume radiation in the three-dimensional wire metamaterial. Some typical numerical results for bunches of various sizes and for various distances from the bunch to the edge structure are presented.

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IMPROVED SEPARATION OF HARD AND SOFT COMPONENTS IN THE MULTIPLE COULOMB SCATTERING DISTRIBUTION

Micola Bondarenco[1]

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Evaluation of the angular distribution function of multiple Coulomb scattering is improved by deforming the integration contour in the Fourier integral representation into the complex plane of impact parameters. That allows to express the distribution function as a sum of two positive components, hard and soft. The soft component is close to a Gaussian, whereas the hard component incorporates the Rutherford asymptotics and all the power corrections to it at large scattering angles, while vanishing in the forward direction. The total number of particles in the so defined hard component logarithmically decreases with the target thickness.

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INFLUENCE OF AN ELECTRIC FIELD ON THE PROPAGATION OF A PHOTON IN A MAGNETIC FIELD

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In this work, a constant and uniform magnetic field is less than the Schwinger critical value. In turn, an additional constant and uniform electric field is taken much smaller than the magnetic field value. The propagation of a photon in this electromagnetic field is investi-gating. In particular, in the presence of a weak electric field, the root divergence is absent in the photon effective mass near the thresholds of pair creation. This is due to the fact that at the formation time of the processes, the particles of creating pair get the additional mo-mentum from the electric field. Thus, there may the sufficiently large width of the Landau levels in presence of a very weak electric field. If this width becomes of the same order or greater than the distance apart Landau levels, these levels overlap and one can use the method of the stationary phase. Under this condition the quasiclassical approach [1] is valid where it is inapplicable in the absence of electric field. In the opposite case for small value of the level width, the quasiclassical method is not applicable near the thresholds. This is the quantum case and we use the new method of studying process [2].

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TRANSFORMATION OF A SYMMETRICAL TM MODE AT THE OPEN END OF CYLINDRICAL WAVEGUIDE WITH DIELECTRIC LOADING

Sergey Galyamin[1]***, Andrey Tyukhtin, Viktor Vorobev***

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Electromagnetic radiation with terahertz frequencies (0.1-10 THz) is supposed to be a promising tool for a number of applications. Efficient terahertz emission can be achieved, for example, using the beam-driven dielectric loaded structures [1]. Under certain approximations, the problem of transformation of a single TM mode with a high number at the open end of a cylindrical waveguide with a dielectric layer was considered recently [2]. Namely, radiation patterns in the Fraunhofer zone were calculated using rigorous Stratton-Chu formulas, but the field at the outer side of the open end aperture was calculated using Kirchhoff approximation and Fresnel coefficients formalism. In this report, we investigate the applicability of approximations utilized above by considering the rigorous problem statement. We develop the method known for solution of corresponding problem in plane geometry [3] and apply it to the case of cylindrical geometry. This technique is combination of the Wiener-Hopf technique and tailoring technique which leads to the infinite linear system for magnitudes of reflected modes. This system can be solved numerically using the reduction technique.

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Section 7

Processes with Crystalline Targets

For Notes

NONLINEAR COMBINATION (RAMAN) SCATTERING OF PHOTONS BY THE CHANNELED POSITRONS

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The channeled particles is characterized by the bound quantum states of its transversal motion. Photon interactions with the channeled particles in a single crystal may be accompanied by the energy transitions between the transverse motion levels of channeling particles. The photon combination (Raman) scattering by the quasi-bound channeled particles leads to the appearance of a frequency combination of the incident photon frequency ω_0 and the frequency $\Delta\omega_{if}$, i.e.

$$\omega_s = \omega_0 \pm \Delta\omega_{if},$$

where $\Delta\omega_{if} = 2\Delta\varepsilon_{if}\gamma^2$; $\Delta\varepsilon_{if}$ is the transition energy between "i" and "f" transversal motion quantum states; $\gamma = E/(mc^2)$ is the channeled positrons Lorentz-factor [1]. A "violet" satellite ("anti-Stokes" lines ω) analysis in the Raman combination scattering spectrum is suggested. Tree photons Raman type transition is examined, i.e. the process of the simultaneous absorption of two photons with the frequency ω_0 and the photon emission with the frequency $\omega_s = 2\omega_0 2\Delta\varepsilon_{if}\gamma^2$. Resonance conditions for the third harmonics observation ($\omega_s = 3\omega_0$) is discussed.

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ON THE FABRICATION AND EXPERIMENTS WITH MICROMETRIC AND NANOMETRIC SILICON PLATES FOR CHANNELING EXPERIMENTS

Giacomo Germogli[a,1], ***Andrea Mazzolari***[a], ***Enrico Bagli***[a], ***Laura Bandiera***[a], ***Vincenzo Guidi***[a], ***Alexei Sytov***[a,b]

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In the last years, thanks to innovative techniques for crystals design and fabrication based on silicon micromachining, micrometric and nanometric thick silicon crystal plates suitable for beam manipulation through coherent interactions and hard radiation generation were produced. Thin bent crystals which allowed for the first time efficient steering of negatively-charged particles at sub-GeV energy (855 MeV at MAMI [1]) were manufactured [2]. Achievement of a rather high deflection efficiency allowed to study radiation emitted by channeled and volume reflected sub-GeV electrons [3]. Similarly, an electron beam in the 1 to 10 GeV energy range was deflected at SLAC [4]. As an alternative scheme, to deflect a charged particles beam a straight crystals whose thickness is half of the oscillation length for planar channeling can be used. Encouraging results were obtained with protons by finely adjusting thickness according to beam energy (92nm thickness at 2 MeV and 26.5 Bxm thickness at 400 GeV).

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EXTRACTION OF CARBON IONS FROM THE U-70 ACCELERATOR IN BEAM LINE 4A BY A BENT CRYSTAL AND MEASUREMENTS OF A BEAM CHARGE COMPOSITION WITH SCINTILLATOR AND SEMICONDUCTOR DETECTOR

***Alexander Afonin*[a], *Evgeny Barnov*[a], *Andrei Yanovich*[a], *Ramazan Nazhmudinov*[b], *Alexander Kubankin*[b], *Alexander Shchagin*[c], *Gennady Britvich*[a], *Yury Chesnokov*[a,1], *Petr Chirkov*[a], *Artur Durum*[a], *Mikhail Kostin*[a], *Vladimir Maisheev*[a], *Viktor Pitalev*[a], *Sergey Reshetnikov*[a]**

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The carbon ions +6C with energy 24.8 GeV/u were extracted from the U-70 ring by a bent Si crystal. The deflection angle of a beam by a crystal was 85 mrad. The measured beam intensity in beam line 4a was about 1E05 particles at 1E09 circulated ions in the ring. The scintillation counters were installed in beam center while the semiconductor detector was installed in 43 mm away from the beam axis. In the experiment, spectra of ionization losses of particles passed through the Si detector of thickness 300 um have been measured. Preliminary results of measurements are presented. The spectrum contains Landau spectral peaks with energies, corresponding to particle charges from 1 to 6. The number of counts in the spectral peaks corresponds to the number of particles in the beam.

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PLANAR AND AXIAL CHANNELING OF RELATIVISTIC ELECTRONS IN HALF-WAVE SILICON CRYSTAL AND CORRESPONDING RADIATION

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Half-wavelength crystal (HWC) is a thin crystal, when a channeled particle experiences only one collision with crystallographic plane during its motion through a HWC crystal. Recently, the authors of Ref. [1] experimentally demonstrated that planar channeled 2 MeV protons were successfully mirrored by a thin silicon HWC. In continuation of this work, the mirroring effect was observed at very high energy at CERN-SPS [2].

In Ref. [3] we performed the detailed experimental investigations and computer simulations of channeling of 255 MeV electrons in the 1 μm thickness silicon HWC. Here, we present new experimental data on planar and axial channeling of 255 MeV electrons in a 0.7 μm Si HWC resently obtained at SAGA LS Facility and comparison with computer simulations. The angular distribution of electrons after penetration through the HWC crystal revealed the number of peculiarities. Also we present calculated radiation spectra from electrons channeled in HWC and compare that with radiation spectra of electrons moving in an arc [4] (never studied experimentally).

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ESTIMATION OF THE SPATIAL SIZES OF ULTRA RELATIVISTIC ELECTRONS BEAM FROM ANGULAR DISTRIBUTION OF THEIR EMISSION IN THIN CRYSTALS

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The use of ultra relativistic electron (positron) emission in thin crystals to estimate particle beam spatial sizes for projected electron-positron colliders [1,2] is proposed. The existing position-sensitive X-ray range detectors and the average path of secondary electrons in a detector restrict the minimum value of the measured beam size to a level of approximately 10 μm, which is far greater than the planned sizes of the collider beams which are less than 100 nm [1,2]. We propose to estimate the electron (positron) beam divergence over the diffracted transition radiation in thin crystals which is predominent in a narrow cone near the Bragg direction for particles energy of greater 10 GeV [3] from angular distribution measurements. The spatial sizes can be obtained from the beam divergence in both planes and the calculated beam emittance or the measured one, which is obtained during the earlier stage of acceleration using optical transition radiation or optical diffraction one. The problem of crystals destruction under the influence of a high intensity electron beam is discussed. The use of surface parametric X-ray radiation [4], where the problem of crystal destruction is almost absent, to measure the electron beam parameters is proposed. This work was supported by a grant from the Russian Science Foundation (Project N 15-12-10019)

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WAVE FUNCTIONS OF CHANNELING ELECTRONS IN REGULAR AND CHAOTIC CASES

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The motion of fast electrons through the crystal under axial channeling could be both regular and chaotic [1, 2]. The chaotic character of quantum systems manifests itself in different ways [3]. The evidence of quantum chaos in statistical properties of energy spectra of channeling electrons had been demonstrated in [4]. In the present report we demonstrate qualitative difference between regular and chaotic cases in individual quantum states, that is in morphology of stationary wave functions for electron channeling in the field of a single [110] atomic string of silicon crystal and a pair of neighboring strings.

This research is financed by the grant of Russian Science Foundation (project 15-12-10019).

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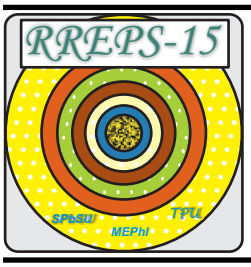

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Poster Session 1

For Notes

ANGULAR DISTRIBUTION FEATURES OF THE CHERENKOV RADIATION AT THE CHANNELING IN THE OPTICAL RANGE

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It is shown that electrons channeled along the (220) planes of the crystal C (diamond), the radiation in the energy range (1.5,12.5) eV is the Cerenkov radiation at the channeling - ChRC (ChRPr-photons) which should be nonuniform in the azimuthal angular distribution. These features of the angular distribution of the channeling radiation (CR) from channeled relativistic electrons (optical range) arise due to interband and intraband transitions between transverse motion quantum states of the electrons at the planar channeling in medium with dispersion ($n > 1$). Based on the features of the accelerator SAGA LS (Japan), we have carried out calculations for the CR from relativistic electrons with $\gamma = 500$. Nonetheless, our calculations have shown that for relativistic electrons with $\gamma \in (20 \ldots 500)$ the features of azimuthal angular distribution of ChRC remain the same.

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ANGULAR-OF-INCIDENCE DEPENDENCE OF TOTAL YIELD OF CHANNELING RADIATION FROM RELATIVISTIC ELECTRONS IN THIN SI AND C CRYSTALS

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The total yield of the radiation from 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 [3].

Here we consider the angle-of-incidence dependence of the total yield of CR from 255 MeV electrons at <100> axial, (100) and (111) planar channeling in 0.7 and 20 μm Si and 50 μm C crystals. 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) [5].

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CALCULATION OF RADIATION BY A CHARGE MOVING IN A DIELECTRIC TUBE

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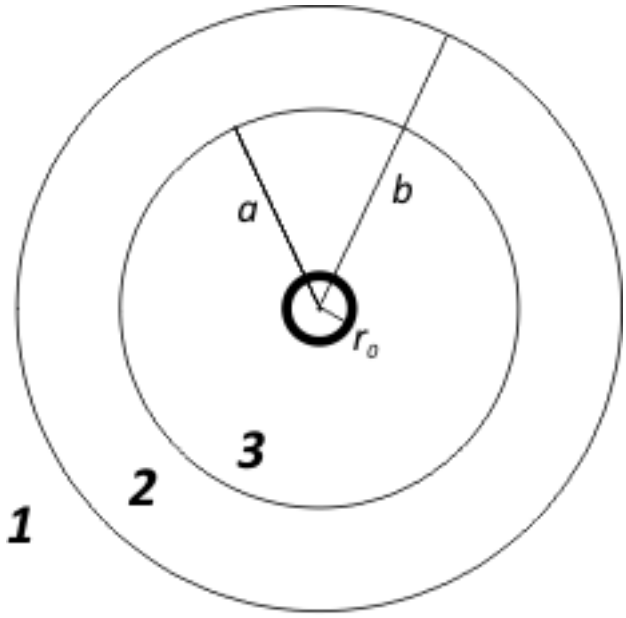
The problem of the generation of electromagnetic radiation generated by the uniform motion of a charge along the axis of the dielectric tube. The tube has a cylindrical symmetry, area 2 (tube body) is a homogeneous dielectric with known values of the dielectric constants (the longitudinal or vortex). It is assumed that a moving charge does not break the cylindrical symmetry of the system. The figure shows a charge as an infinitely thin ring centered on the axis of the tube.



The problem is solved with the help of Maxwell's equations for the vortex fields. As it is known, the vortex current is only part of the total current, providing by a driving charge. In contrast to the total current it contains non-localized part. This fact is explicitly taken into account in the calculation. The paper discusses the influence of the delocalization of current on the stopping force.

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CHARACTERIZATION OF MULTI-STRIP CRYSTAL DEFLECTOR FOR HIGH ENERGY PROTON BEAMS BY SYNCHROTRON RADIATION TOPOGRAPHY WITH ANGULAR SCANNING

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Currently, for the extraction and collimation of the proton beams at the large accelerators, bent silicon single crystals are used. The device for multiple deflection of the proton beam by several curved strips of silicon in the reflection mode has been developed recently. The device consists of several strips, divided by grooves, on the surface of a thick plate of silicon. Bending of the strips is achieved by internal stresses in the material due to the Twyman effect. Method of X-ray topography with angular scanning, performed at synchrotron radiation, was used for measurement of the bending of the individual strips of the deflector and the crystal as a whole. The measurement results are compared with the results obtained previously in the proton beam.

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COHERENT BREMSSTRAHLUNG FROM NEUTRONS

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The neutron has a spin and anomalous magnetic moment and, therefore, it can interact with electromagnetic field. Schwinger [1] was the first who predicted that fast neutrons can be scattered by atom electric field due to their magnetic moment. The Schwinger scattering of fast neutrons by the atoms was experimentally proved in 1956 [2].

Another mechanism of neutron interaction with electromagnetic field is photon emission from neutrons. For the first time, an emission of the photons from neutrons in an external magnetic field was theoretically studied in [4-6]. This new type of radiation produced at interaction of the anomalous magnetic moment and magnetic field was named "spin" light [6]. Bremsstrahlung and coherent bremsstrahlung from neutrons was considered in [6-8].

It is well known that in addition to the electromagnetic interaction, the neutron takes part in the strong interaction. In the paper [9] it was investigated the contribution of strong interaction of neutron into coherent neutron scattering in the crystals.

In the present report we studied the influence of strong interaction of neutron on coherent bremsstrahlung from neutrons. The results of calculations show that coherent effects exist not only for bremsstrahlung due to electromagnetic Schwinger scattering, but also for bremsstrahlung due to nuclear and interferential scattering of fast neutrons.

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COMPARISON OF THE QUANTUM AND CLASSICAL CALCULATIONS OF FLUX DENSITY OF (220) CHANNELED POSITRONS IN SI CRYSTAL

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The flux-peaking effect (FPE) of channeled particles is one of the known orientation effects at channeling [1].

In this work we investigated the conditions that necessary to observe of FPE at (220) planar channeling of 255 MeV positrons in thin Si crystals. For the FPE description of channeled positrons the numerical calculation of flux dynamics were performed in the frame of quantum and classical description. Comparison of results of quantum and classical calculations were performed. The results obtained by the two methods reveal a good correlation. In particular the number of probability densities peaks of positrons in case of quantum description coincide with number of spatial distribution peaks for classical description.

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COMPUTER MODELING OF ELECTRON-POSITRON PAIR PRODUCTION BY CHANNELING RADIATION IN AMORPHOUS CONVERTER

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The radiation from the high energy (up to 10 GeV) electron beam is known to be reasonably effective positron source. An approach being possess high efficiency is to use electron beam for production of channeling radiation (CR) in a crystalline target (radiator) and subsequent electron-positron pair production in amorphous target (convertor), so called a "hybrid" solution [1].

The Mathematica [2] code BCM-1 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 perform the comparison of the positron yield in a thin amorphous W converter produced by bremsstrahlung, by axial <100> and planar (110) channeling radiation in a W crystal [3].

Here we consider the radiator-converter approach at 200 MeV channeled electrons (the SPARC facility energies) for the case of using W crystalline radiator and Si, Ge and W amorphous converters. Computer modeling is carried out taking into account electron dechanneling at planar channeling in the radiator and positron stopping in the convertor.

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DISTRIBUTION OF THE YIELD OF X-RAYS PRODUCED IN THE PYROELECTRIC ACCELERATOR ON THE PYROELECTRIC CRYSTAL SURFACE

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Electrons accelerated in the pyroelectric accelerator hit the surface of the pyroelectric crystal. Results of the experimental research of the distribution of X-rays produced by the electrons on the pyroelectric crystal surface are presented and discussed. The maximum yield X-rays was observed in the center of the crystal.

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DUAL-WAVE X-RAY ABSORPTIOMETRY IN MULTIPHASE FLOW METERING

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The authors propose a brand new technology named dual wave absorptiometry. This technology, which is a special case of X-ray wave dispersive spectroscopy, can be used for determination of component composition of the media containing limited number of components, for example multiphase fluids, that is topical issue for modern oil and gas industry. A detailed description of the proposed technology is given in the report as well as numerical simulating and experimental results. Nowadays devices for this kind of analysis based on use of gamma radiation produced by radioactive source, e.g. 133Ba, are most common. The main peculiarities of the proposed technology are the use of tunable X-ray source, namely X-ray tube or compact electron accelerator, to produce radiation and a set of crystal monochromators-analyzers for synchronous analysis of the absorption extent for X-ray with different energies. Test experiments have shown that sensitivity of the technology is not less than 0.1% by mass per measurement time equal to 1 second with statistical error of less than 1%. In comparison with existing analogues the proposed technology provides a better accuracy and sensitivity due to a greater flux of the separated energy lines of radiation, which is 2-4 orders higher than the one produced by radioactive sources. Additionally, non-use of radioactive isotopes improves ecological and radiation safety.

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GENERATION OF PULSED NEUTRON BEAM BY CHANNELING RADIATION FROM RELATIVISTIC ELECTRONS

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As is well known, the channelling radiation (CR) from sub-GeV relativistic electrons is characterized by brilliant peak in intensity at the photon energies within 1-5 MeV. These photons may lead to the photonuclear reaction (gamma, n) in the downstream target consisting of nuclei with appropriate neutron binding energy. Since the CR spectrum and its maximum position depends on the initial electron beam energy, the neutron yield is complicated function of the electron beam energy. Here, we present the results of calculations of the neutron yield generated by CR from initial electrons with energies 200 - 800...1600 MeV (SPARC Facility, LNF) channeled in a Si, Ge and W crystals, which is directed to Be or D target. The comparison with other methods of generation of fast neutron beams (with neutron energy up to several MeV) is performed, especially with so called "neutron focus in the field of synchrotron radiation"

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INFLUENCE OF ABSORBTION ON THE X-RAY DIFFRACTION BY THE TRAPEZIFORM MODEL OF SUPERLATTICE WITH A STACKING FAULT

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The problem is considered of a dynamic reflection of a plane monochromatic X-ray wave at the trapeziform model of superlattice with a stacking fault between layers when absorption is taken into account.

When a plane monochromatic X-ray wave is incident on a superlattice double diffraction occurs, first by atomic planes causing the formation of a modulated X-ray wave in the crystalline medium, and then by diffraction of the latter by the interfaces between layers, since the layer structure acts as a diffraction grating. Being important in applications, superlattice perfection has been investigated by various methods of X-ray and electron microscopy analysis. One of the possible defects impairing superlattice parameters is a stacking fault.

In this paper we develop the theory of X-ray diffraction on trapeziform model of one-dimensional superlattice with a stacking fault between the layers when absorption is taken into account.

As is known, the interference absorption factor of a multilayered crystalline system has oscillating character. We obtained, that presence of stacking fault reduces the interference absorption factor, maintaining its oscillations. At the same time, the closer stacking fault is to the crystalline surface, the less impact it has on the interference absorption factor.

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INFLUENCE OF CURVATURE ON THE CRYSTAL SURFACE POTENTIAL

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Nowadays a strong effort is put into research of nanostructures formation (shaping/creation) both on the surface and inside solid state specimens. Such an intention is dictated by a constant drive for interfaces miniaturization in submicron electronics and allied research areas. Hence, so called mesomaterials, e.g. cellular materials or capillary structures, are of a great interest. For instance, those polycapillary structures are widely used for manipulation of neutral particles (photons of X-ray and γ frequencies, neutrons, atoms). One of the most recent examples is related to the use of a microcapillary plate as an X-ray optics element. The theory of X-ray and neutron beams propagation through such systems is well developed and experimentally proved.

Talking about particles interaction with capillary structures, we still lack a generalized description of charged particles interaction with a curved surface. Basing on a yearly project results, we analytically describe such interaction of a charged particle with curved surface of a crystal in a very simple approximation.

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METHOD OF FORMING PROFILES OF ARBITRARY ELECTRON BEAMS

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Electron beams has been widely used in many application fields. Using electron beams generally requires their ability to control characteristics such as beam shape, spectrum and equitability. There are sets of collimators, filters and flutter in industrial plants to settle the issue. However, sometimes there are problems that cannot be solved by means of the existing sets. Besides of that, there are always tasks that require the formation of electron beams or small series of experimental sources for which there is no standard set of filters, collimators and flutter.

This paper presents a method to create a device for generating arbitrary electron beams. The method is based on experimentally obtained characteristics of electron beams, creating a mathematical model of electron beam, calculation of filter parameters and flutter. To produce filters and flutter is provided by means of rapid prototyping method. Samples calculated using fused deposition modeling, are made of specific density plastic material.

The proposed method will significantly simplify the work with electron beams in the cases when it is necessary to have exactly required shape and intensity distribution of the beam.

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MULTI-PHOTON ABSORPTION IN THE CHANNELING OF ELECTRONS IN AN EXTERNAL FIELD

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Following the methods developed for atom ionization by alternating electric field the probability of multi-photon absorption of photons of the strong external laser field by channeled electron (ejection of electron from the channel, photo-ionization) have been calculated for different strengths of the external field and different levels of electrons in a planar channel. The emission spectra of 54 MeV electrons channeled in diamond crystal planes (110) are shown for different values of the resonant laser control field of a frequency close to the transition frequency in the channel with and without photo-ionization. It is shown that the ionization probability is less than the probability of electron scattering in the crystal and make a small contribution to the total level width.

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OPTICAL RADIATION FROM CHANNELED RELATIVISTIC HEAVY IONS IN VICINITY OF THE CHERENKOV ANGLE

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The Cherenkov radiation (ChR) from relativistic charged particles moving uniformly and rectilinearly with constant velocity in an optically transparent radiator is described by the well-known Tamm-Frank theory. Several reasons may lead to deviations from this ideal character of motion: 1) multiple scattering – a particle velocity vector changes and angular distribution becomes broadened; 2) stopping in a radiator – a particle velocity decreases, the Cherenkov angle changes; 3) channeling effect. Multiple scattering and channeling are concurrent processes and in a thin crystal the deviation from rectilinear trajectory is mainly due to periodic transverse oscillations between crystallographic planes. Here, the ChR from channelled RHI in an optically transparent diamond crystal is investigated in detail. We analyze: a) the shift of both ChR spectral and angular distributions maxima compared to the standard Tamm-Frank theory due to taking account of periodic deviation of the channelled RHI velocity vector from the average one; b) dependence of the ChR intensity on the azimuthal angle; c) influence of slowing-down due to ionization energy loss. The effects predicted strongly depend on the channelled RHI energy and are closely connected to the normal and anomalous Doppler effects in emission from an oscillator moving in the medium.

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ORBITAL ANGULAR MOMENTUM OF CHANNELING RADIATION FROM RELATIVISTIC ELECTRONS

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Electromagnetic field is proven [1] to possess an intrinsic angular momentum. Using the developed code BCM-1 [2] the orbital and spin angular momentum of the channeling radiation (CR) from positrons in the thin Si crystal was considered in [3] in the frame of classical approach. The Mathematica [2] 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.

Here we consider the orbital angular momentum (OAM) of the radiation from electrons at (110) planar and <100> axial channeling in the thin 0,7 and 20 Bxm Si crystal. The angular-of-incidence dependence of total CR OAM and the influence of the crustal thickness are investigated. The energy of electrons is chosen to be 255 MeV in accordance with the experimental setup at linear accelerator at SAGA-LS (Japan) [4]. The possibility of experimental detection of such properties of channeling radiation is discussed.

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ORIENTATION EFFECTS FOR THE GRAZING INTERACTION OF FAST ELECTRONS WITH A DIELECTRIC SURFACE

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A series of experiments has been conducted to investigate the spectral and angular characteristics of the beam of fast electrons interacting with dielectric surfaces in a grazing mode. The cases of flat, conical and surface-structured targets were considered. The experimental results have shown the ability to control the angular characteristics of the electron beam when changing the orientation of the plane or the axis of the target relative to the axis of the electron beam.

The results make it possible to create a model of the processes occurring for grazing interaction of electrons with the dielectric surfaces and rely on the use of these processes to develop effective devices to manage spatial characteristics of electron beams with energy of 10 keV. Furthermore the experimental results show the possibility to "press" the beam of fast electrons towards the surface of the combined metal-dielectric sample (and increase the total time of interaction) in order to study more efficiently the radiation arising during electron movement above the periodically structured surface.

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PAIR CREATION BY CHANNELED PARTICLES

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Relativistic charged particle passing through a crystal at small incident angle with respect to a crystal plane can be captured into channeling state [1-3]. The channeled particle has the transverse discrete energy levels. Due to the transition from one transverse energy level to another it can emit a photon. In higher-order of the perturbation theory, instead of the photon it can emit an e^+e^- pair [3,4].

In the [3] the pair creation by the channeled charged particles was considered in semi classical approximation and in the [2] it was considered as channeling radiation and following e^+e^- pair creation by photon in a crystal.

In the present paper for the first time we considered electron-positron pair creation by the channeled positron and positron in a frame work of QED. The calculation is similar to the calculation of e^+e^- pairs in the recombination of the electron with the nucleus [4,5].

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QUANTUM RESONANCES IN SMALL-ANGULAR POSITRONS AND ELECTRONS REFLECTION

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The physical reason of predicted phenomena, similar to the band structure of transverse energy levels, is connected with the Bloch form of the wave functions of electrons (positrons) near the crystallographic planes, which appears both in the case of planar channeling of relativistic electrons (positrons) and in reflection by a crystal surface. Calculations show that positions of maxima in reflection of relativistic electrons and positrons by Pѳ crystal surface specifically depend on the angle of incidence with respect to the crystal surface and relativistic factor of electrons/positrons. These maxima form the Darwin tables similar to that in ultra-cold neutron diffraction. Calculations show that if the particle energy is fixed, the reflection coefficient value specifically depends on incidence angle. Increase of the electrons energy leads to decrease of the distance between the Darwin tables. In contrary, with increase of the angle of incidence of electrons to the crystal surface, the distance between the Darwin tables increases as well. Our results demonstrate that the effect of small-angular positrons and electrons reflection can be experimentally observe.

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QUASICHARACTERISTIC RADIATION OF RELATIVISTIC ELECTRONS AT ORIENTATION MOTION IN LITHIUM HALIDES CRYSTALS ALONG CHARGED PLANES AND AXES

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In [1] the planar channeling and quasicharacteristic radiation (QCR) in charged planes (111) of ionic crystals LiH, LiD and LiF were studied. In the report the potentials of electron interaction with charged planes (111) and charged axes [110] of LiF crystal, as well as in other crystals of lithium halides (LiCl, LiBr and LiI) are calculated by methodic [2]. It is shown that the contribution of the Coulomb component into the structure of potential wells both in planar and axial cases is very essential. It is shown also that potential wells in Li^+-planes of and crystals don't disappear up to the melting temperature. From the other hand in and crystals these wells are inverted into potential barriers at T=600K and T=450K respectively. The similar effects take place at axial channeling.

On the basis of the numerical solution of SchrГ¬dinger equation the energy levels and wave functions for the relativistic electrons channeling along (111) planes and along [110] axis are found. In a dipole approximation the spectra of QCR are calculated for various regimes of channeling.

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RADIATION AT MOVING OF CHARGE IN TUBE

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It is of a special interest to calculate the radial and longitudinal components of polarization forces for charged particles channeling in tubes (capillaries, pores in the solid films, nanotubes). But dielectrics, as a rule, obey different reaction on the external vortex or potential electromagnetic fields. The polarization properties of homogeneous media described with the help of vortex and potential dielectric susceptibilities, which are generally speaking not coincide. In a case of non- homogeneous media taking into account of this difference seems to be perfectly inevitable. The linearity of Maxwell equations makes it possible the independent consideration of two mentioned kinds of field. The calculation of potential polarization fields as well as the corresponding forces was performed in a number of works, in opposite to what concerns the vortex fields. The density of electrical currents produced by both polarization and external charges should also be subdivided into vortex and potential components. We emphasize that point charge generate as the potential current as well the vortex one. Both the currents are delocalized. In present work we consider more in detail the influence of mentioned delocalization on the radiation effects in tubes.

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RADIATION OF THE MAGNETO-CRYSTALLINE UNDULATOR

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The radiation at grazing incidence of relativistic positively charged particles on the crystal surface in the presence of magnetic field is studied theoretically. The magnetic field is supposed to be parallel to the surface and orthogonal to the velocity of particles. Dependent on the initial conditions the particle can be captured in the channeling mode and perform periodic oscillations near the surface of the crystal. The appropriate initial conditions for the transverse energy of the particle are found. The spectrum, angular distribution and polarization of radiation are calculated. The emission spectrum of a single particle is discrete and it extends up to very large numbers of harmonics. If the magnetic field is much weaker than the electric field of atoms, the frequency range of radiation of the particle beam does not depend on magnetic field and is defined only by the energy of the particles and by the surface averaged potential, though the frequency of the first harmonic is defined solely by the magnetic field. The photon energy at the cut-off edge of the spectrum in case of positrons is of order $10\gamma^{3/2}$ (eV), where γ is the particle relativistic factor. The main part of radiation is concentrated in a narrow cone in the direction of initial velocity of the particles and is polarized largely in the plane orthogonal to the surface of the crystal.

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SCATTERING OF ELECTROMAGNETIC WAVE BY DIELECTRIC CYLINDER IN EIKONAL APPROXIMATION

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The fiber-like structures are widely used for control of electromagnetic radiation propagation (waveguides etc., see [1] and references therein). The problem of the wave propagation through the rope of parallel fibers was considered in [2] for the limiting case of small angle of incidence and infinitely thin fiber. The radiation scattering in that case possesses the axial symmetry around the fiber axis. In the present report we calculate the radiation cross section on the fiber of finite radius and arbitrary internal structure using eikonal approximation.

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SIMULATIONS OF CHARGED BEAMS INTERACTION WITH ELECTROMAGNETIC STANDING WAVE

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Recently it was shown that charged particles motion in the field of standing electromagnetic wave can undergo the features similar to the particles channeling in crystals [1]. While a charged particle enters the channels formed by electromagnetic standing waves at a small angle to the node (anti-node) planes its motion represents namely the oscillations between two neighboring planes. The phenomenon is mostly known as channeling in a lattice of the standing waves. Obviously, this effect can be used to manage beams in accelerator physics, more general, for the beam shaping with the properties which one desires [2]. Additionally to the feasibility of beam shaping by standing waves for electron, positron and muon bunches, the report illustrates the code ability for simulating fine peculiarities of real beam of various spatial and angular distributions that interacts with the complex structure of laser intersection area.

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STARK EFFECT FOR RELATIVISTIC HEAVY LI-LIKE IONS PLANAR CHANNELED IN A CRYSTAL, RESONANT COHERENT EXCITATION AND CORRESPONDING RADIATION

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The Stark effect causing splitting and mixing of electronic levels in the channeled relativistic heavy ions (RHI) is investigated. For hydrogen-like RHI the linear Stark effect in the electric field of the crystal planes, along with a fine splitting of the electronic levels of channeled RHI, is the main reason of the Resonant Coherent Excitation (RCE) peaks broadening.

Recent experiments on RCE have been performed with beams of heavy ($Z \gg 1$) He and Li-like Argon and Uranium RHI at HIMAC and at SIS-18 GSI. To correctly explain the experimental data, it is necessary to calculate the Stark effect, mixing and splitting the electronic levels of channeled RHI in the electric field of the crystal planes, which in turn effects the broadening of radiation spectra from coherently excited in a crystal RHI. In this work, we studied the depending on the position in the channel Stark effect for channeled Li-like RHI. The results of calculations are compared with experimental data. Moreover, since the dependence on relativistic factor of channeled RHI is different for linear and quadratic Stark effects, we predict some new peculiarities of RCE and corresponding radiation spectra.

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THE DEPTH OF PENETRATION OF SLOW TRANSVERSE WAVES IN THE PLASMA INTERACTING WITH LASER BEAT WAVES

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The self-consistent kinetic equation describing the state of collisionless plasma with an initial distribution of the Maxwell interacting with laser beat waves (LBW) is solved. For study the spectra of transverse electromagnetic waves are received the dispersion equation and expression for the dielectric permittivity. Analysis of the dispersion equation for the slow transverse waves was conducted. It is shown that the skin effect is manifested in a lower frequency region than it was previously accepted. When interacting with the plasma LBW skin effect is suppressed and passes from anomalous dispersion to normal dispersion. Wherein slow transverse waves is amplified.

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THE RADIATION OF A POSITRON IN THE CRYSTALLINE WIGGLER

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In the crystalline Wiggler (CW) channeled positron oscillates both the higher and less frequently due to the curvature of the planes in the crystal. The parameter of the Wiggler is much greater than unity, the main contribution to the radiation give higher harmonics, the spectra of which overlap. Radiation is emitted at a small angle in the narrow layer containing the plane of motion of the positron.

Classical theory is applicable in a limited interval of frequencies. Because when considering the theory of radiation taking into account the photons with large frequency,energy losses becomes of the order of energy positron.

We find the boundary frequency when the positron loses all its energy, of course, that the problem should be solved in the framework of quantum theory, taking into account energy losses.

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THE THERMAL STRESS AT SHORT ELECTRON BUNCHES PASSAGE THROUGH A THIN TARGET

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The thin target could be used for beam diagnostics by means the radiation that is induced by interaction of beam particles with target matter [1-3]. The electron beams used in modern applications (as, for example, modern FEL-s) have very large brightness, small emittance as well as very short bunch length. For example, the bunch length of XFEL is about of 25 um at bunch charge 1 nC and with electrons energy of 17 GeV [4]. The passage of this powerful short bunches could damage the target or even completely destroy it. In the presented work both the heating when the train of such bunches passages through the target and the corresponding thermal stress are investigated. It is shown the target works in extreme regime close to phase transition temperatures and stress limits. The model to investigate these extreme regimes is developed.

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TOTAL WAKE FIELD IN A RECTANGULAR ACCELERATING STRUCTURE WITH DIELECTRIC ANISOTROPIC LOADING

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Dielectric lined waveguides are under extensive study as accelerating structures that can be excited by electron beams. Rectangular dielectric structures are used both in proof of principle experiments for new accelerating schemes and for studying the electronic properties of the structure loading material. Some of the materials used for the waveguide loading of accelerating structures (like sapphire) possess significant anisotropic properties. General solutions for the fields generated by a relativistic electron beam propagating in a rectangular dielectric waveguide have been derived using the mode expansion method for the transverse operators of the Helmholtz equation. An expression for the combined Cherenkov and Coulomb fields obtained in terms of a superposition of LSM and LSE-modes of rectangular waveguide with anisotropic dielectric loading has been obtained. Numerical modeling of the longitudinal and transverse (deflecting) wakefields has been carried out. It is shown that the dielectric anisotropy influences to excitation parameters of the dielectric-lined waveguide with the anisotropic loading.

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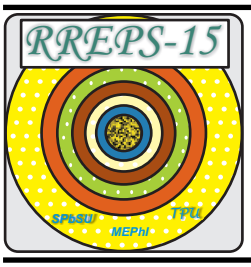

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6-11 September 2015, Saint Petersburg, Russia

Section 3

Parametric X-Radiation

For Notes

KINEMATIC THEORY OF THE PARAMETRIC X-RAY RADIATION WITH USE OF THE FRESNEL COEFFICIENTS

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The parametric X-ray radiation (PXR) is considered as a result of the diffraction in a crystal of virtual photons associated with relativistic charged particle moving through the crystal. Formulas for PXR Fresnel coefficients are obtained in kinematic approach and applicability of the approach is discussed. The development of the kinematic PXR theory version with use of the Fresnel coefficients is shown. Besides, analytical expressions for frequency, spectral peak width, differential by angles yield of the PXR, and its polarization are derived with use of the Fresnel coefficients. It is shown that the obtained expressions are in good agreement with results of kinematic PXR theory by Ter-Mikaelian and results of experimental research of the main properties of the radiation in the PXR reflection. Areas of applicability of the dynamic and kinematic theories of the PXR are discussed.

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LINEAR THEORY OF SELF-AMPLIFIED PARAMETRIC X-RAY RADIATION FROM HIGH CURRENT DENSITY ELECTRON BUNCHES

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The operation of synchrotron x-ray light sources and free electron lasers opened new era in the investigation of matter on Angstrom lengthscale with fs time resolution. However, need for GeV electron accelerators and hundreds meter long undulator modules results in high construction, which makes the existing facilities extremely overbooked. In recent years there were investigated several mechanisms that could lead to compact lab-size bright and coherent x-ray sources. In this contribution we will theoretically analyze the possibility to achieve the x-ray lasing from 100 MeV electrons in mm thick crystals based on the parametric beam instability effect. This effect was predicted by Baryshevsky and Feranchuk in 1983, they showed that above threshold current density value the interaction between parametric x-ray radiation electric field and relativistic electrons leads to instability and exponential growth of radiated intensity. This effect was realized in the THz range with artificial periodic structures, but for x-rays and crystals the threshold current density was estimated to be 10^9 A/cm^2; such current density values became recently available from short electron bunches. In this contribution we will review the linear theory of parametric beam instability, discuss the optimal geometries for the instability growth and generation of induced radiation from shot noise.

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COMPARISON OF DTR SPECTRAL-ANGULAR CHARACTERISTICS OF DIVERGENT BEAM OF RELATIVISTIC ELECTRONS IN SCATTERING GEOMETRY OF LAUE AND BRAGG

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Diffracted transition radiation (DTR) generated by divergent beam of relativistic electrons crossing a single-crystal plate in different (Laue, Bragg) scattering geometry have been considered for general case of asymmetric reflection of electron coulomb field relative to the entrance target surface. The expressions for spectral-angular density of DTR and parametric X-ray Radiation (PXR) are derived. Then DTR and PXR have been considered in case of thin target, when multiple scattering of electron is negligibly small, that is important for divergence measurement in real time rГкgime. Numerical calculation of spectral-angular density of DTR by a beam of relativistic electrons have been carried out with use of averaging over the bivariate Gauss distribution as angular distribution of relativistic electrons in the beam. It have been shown that in Bragg scattering geometry DTR has bigger angular density, than in Laue geometry what can be explained by existence of the frequency range, in which the incident wave propagation vector takes complex value even under absence of absorption. In this range all of photons will be reflected. It's mean that the range of total reflection defines the width of DTR spectrum.

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PARAMETRIC X-RAY RADIATION FROM RELATIVISTIC ELECTRONS INTERACTING WITH A TEXTURED POLYCRYSTALS

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The characteristics of Parametric X-ray radiation (PXR) from crystalline and polycrystalline targets (in the last case also called polarization bremsstrahlung (PB)) are well studied. An important task to be performed in this field is the measurement of the radiation spectral-angular characteristics from textured polycrystalline targets because such interaction represents the transition between crystalline and polycrystalline targets.

This work is devoted to PXR generated during the interaction of a 7 MeV electron beam with a textured tungsten polycrystalline foil. The spectra and orientation dependences of PXR for the (200) plane were measured for the following observation angles: 90°, 120°, 150° and 180° relative to the direction of the emitting electrons propagation. New results of PXR peculiarities at spectral and orientation distributions were observed: the PXR peak position changing when the orientation angle between the electron beam and the target surface changes; the shift of PXR spectral peak to an anomalous diffraction region (PXR was observed at an energy smaller than the lowest possible energy obtainable for free X-rays diffraction); the observation of a broadening of the PXR orientation dependence when the observation angle approaches to 180°.

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SPATIAL DISTRIBUTION OF PXR GENERATED BY 855 MEV ELECTRONS. COMPARISON OF SIMULATION RESULTS WITH EXPERIMENTAL DATA

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The authors of the papers [1,2] proposed to measure the transverse size of an electron beam using the PXR spatial distribution at short distances between a crystalline target and a detector. The experiment described in Ref. [3] was performed with the 855 MeV electron beam of the MAMI-B microtron and a 50 μm thick silicon crystal (100) acting as target, which was oriented under a Bragg angle of 11.25 deg. PXR with energies $h\omega(220) = 16.55$ keV and $h\omega(400) = 23.40$ keV was detected using an X-ray camera (ProxiVision HR-25) with spatial resolution of about 30 μm [4]. The obtained results confirmed the possibility to utilize such measurements for electron beam size estimation. However, the results of this experiment are not well described by the kinematic PXR theory.

The detailed data treatment of the experiment [3], taking into account the contribution of both diffracted transition radiation and bremsstrahlung, is presented in this report. The X-ray camera efficiency was additionally taken into account. The simulated PXR pattern as a whole agrees with the experimental one. However, along the Bragg direction where the influence of the beam size on the PXR spatial distribution is most noticeable, a discrepancy between the model and the experiment is observed. Possible reasons of such discrepancy will be discussed.

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EFFECT OF TEMPERATURE GRADIENT ON PARAMETRIC X-RAY RADIATION. STATUS OF EXPERIMENT

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This work is devoted to investigations of PXR which is generated by 20-50 MeV electrons in the X-cut quartz single crystal at the presence of the temperature gradient. For this propose the beam line LEA-50 (YerPhI) has been constructed with the beam spot diameter of 1 mm, the beam energy spread up to 1%, the beam current up to 0.1 μA.

At the first stage we have investigated X-ray diffraction by the quartz single crystal in Laue geometry influenced by the temperature gradient using the beam of X-ray tube radiation. It has been experimentally shown that intensity of the reflected beam depends on the temperature gradient value and can be increased 2 orders at least. It is shown that by means of the temperature gradient impact it is possible to separate a beam with high angular and spectral width from the white X-ray tube spectrum, to change the direction of reflection and to tune the focus distance.

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PARAMETRIC X-RAY RADIATION FROM DIVERGENT COMPOSITE BUNCHES IN KINEMATIC THEORY

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Some years ago parametric X-ray radiation (PXR) was suggested as a good tool for bunch diagnostic[1], and recently this method was confirmed experimentally[2]. In the theory of PXR there exist two main approaches, kinematic and dynamical ones. The dynamical theory of PXR for divergent beams was suggested in paper[3]. In this article the Gaussian distribution was used to describe the divergence of the electron beam. This supposition can be considered only as approximate one; for more physically appropriate description should be used[4].In this article we continue to construct the kinematic theory of PXR for composite bunches, consisting of two fractions of charged particles with different charges and distributions. The results coincide with our last ones for PXR for composite bunches in case there is no any divergence[5]. We suppose the scedastic distribution of the charged particles in the composite beam and discuss the possibility to get the information of the structure, the divergence, and ionic composition of the bunch with help of PXR.

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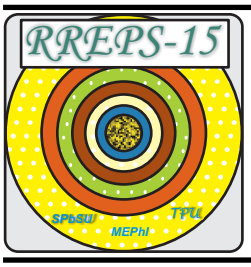

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Section 5

Coherent Bremsstrahlung and Channeling Radiation

For Notes

STATUS AND PERSPECTIVES FOR CHANNELING PHYSICS: FROM CRYSTAL UNDULATORS TO CAPILLARY WAVEGUIDES

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Channeling is the phenomenon well-known in the world mostly related to the propagation of the beams of charged particles in aligned crystals. However, recent studies have shown the feasibility of channeling phenomenology application for description of other various mechanisms of interaction of charged as well as neutral particles beams in solids, plasmas and electromagnetic fields covering the research fields from crystal based undulators and collimators to capillary based x-ray and neutron optical elements.

This review talk will be devoted to actual channeling projects realizing at different centres within international and national collaborations. The future possible developments in channeling physics will be analyzed.

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ON THE RADIATION EMITTED BY SUB-GEV ELECTRONS IN A BENT CRYSTAL

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Electromagnetic radiation emitted by channeled and volume reflected sub-GeV electrons in a bent crystal was measured at MAMI (Germany). A 855 MeV electron beam hit a mechanically bent 30.5 μm thick Si crystal. Crystallographic directions and holder design are optimized to excite quasi-mosaic effect of the (111) planes, while thickness was reduced down to the order of the dechanneling length (15-20 μm) [1]. Electromagnetic radiation emitted was more intense than for the amorphous case both for channeling and volume reflection. In addition, intensity of radiation accompanying volume reflection is maintained high in the whole angular acceptance, which is equal to the bending angle of the crystal [2]. Radiation accompanying coherent interactions at this energy is of special interest for the realization of an innovative intense source of X-ray via channeling in a periodically bent crystal. Experimental results on dynamics and on radiation generation were critically compared to Monte Carlo simulations.

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COHERENT BREMSSTRAHLUNG ON A DEFORMED GRAPHENE SHEET

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We investigate the coherent bremsstrahlung from electrons moving at small angles with respect to a deformed graphene sheet. For an arbitrary periodical deformation of the sheet, a formula is derived for the corresponding cross-section as a function of the radiation direction and frequency. The conditions are specified under which the coherent effects dominate in the total cross-section. In dependence of the parameters of the deformation field and of the angle between the electron momentum and the crystallographic axes of the graphene lattice, the presence of the deformation can either enhance or reduce the bremsstrahlung cross-section.

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ANGULAR DISTRIBUTION AND XANES SPECTROSCOPY OF CHANNELING X-RAY FLUORESCENCE AT THE EXIT OF GLASS MICRO-CHANNEL PLATES

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Propagation of X-rays through microcapillaries is a phenomenon of great interest due to the high efficiency in the transport of the radiation by microcapillary holes and, as consequence, due to the possibility to design new optical elements suitable to shape an intense x-ray beam. Actually, because the technology based on the capillary optical elements can deliver a high flux density within a sub-micrometer spot.

We present here recent experimental data on the transmission of soft X-ray synchrotron radiation collected with different types of micro-channel plates (MCP). We have studied both spectral and angular distributions of MCPs having spatial regular holey channels with a hexagonal symmetry in the transverse cross-section.

To characterize the fine structures of the energy spectra and angular distributions of the fluorescence radiation at the exit of MCPs we have also measured the soft X-ray transmission at both Si-L and O-K edges. Based on this large set of experimental data, theoretical calculations were performed to clarify the soft x-ray channeling phenomenon giving unique information on the wave propagation phenomenon. Indeed, both experimental and theoretical data point out the presence of propagation radiation modes in these glassy waveguides and the interference between incident and reflected (fluorescence) waves inside MCPs.

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POLARIZATION BREMSSTRAHLUNG OF FAST ELECTRONS ON METALLIC NANOSPHERES IN DIELECTRIC MATRIX WITH ACCOUNT FOR PLASMONIC INTERFERENCE EFFECTS

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The presentation is devoted to theoretical analysis of Polarization Bremsstrahlung (PBrS) [1] due to the scattering of fast electrons on metallic nanosphere embedded in dielectric matrix in frequency region near dipole and quadrupole plasmon resonances. Here we account for plasmonic interference effects which arise in frequency-angular distribution of PBrS. These effects are the consequence of interrelation between contributions in PBrS due to plasmon on sphere surface with different multipolarity. Our approach is based on the Fermi method of equivalent photons [2] and Mie theory of radiation scattering on small metallic particles [3].

It is shown that the account for plasmonic interference in PBrS differential cross section leads to specific features in spectral distribution of emitted photon which strongly depend on radiation angle, nanosphere radius and dielectric permittivity of matrix.

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POSITRON BUNCH RADIATION IN THE SYSTEM OF TIGHTLY-PACKED NANOTUBES

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In the present work investigated the problem of radiation of positron bunch in the system of the packed nanotubes. In this work used model of the harmonic potential which is justified since on the one hand the number of positrons near the axis of the nanotubes region is small, and on the other hand their contribution to the formation of the total radiation is also small. The problem is solved in the dipole approximation. Due to the polarization of the medium the first harmonic radiates both extremely hard and extremely soft photons at zero angle.

The frequency-angular distribution of number of photons which is emitted by channelling positrons of bunch is received. It does not depend on the azimuthal angle, since the task has cylindrical symmetry. Photons which is emitted at a zero angle have circular polarization. Radiation have energy threshold: lower threshold is due to the polarization of medium of nanotube, the upper threshold depends on the amplitude of the oscillations of channelling positrons. When the energy of the bunch coincides with the upper threshold, the radiation contribute all channeled positrons. Each a positron in average radiates a one photon. Thus is formed intensive enough quasi-monochromatic, circularly polarized submillimeter photon beam, which may have important practical application.

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XI International Symposium

"RREPS-15"

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Section 2

Transition Radiation

For Notes

PROJECT OF THE SUPERPOSING BEAMLINE FOR PARAMETRIC X-RAY RADIATION AND COHERENT TRANSITION RADIATION IN THZ REGION AT LEBRA

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The new project of a THz-wave light source is in progress at the parametric X-ray (PXR) beamline of the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University. The THz-wave source is based on coherent transition radiation (CTR) emitted from a metal foil inserted downstream of a crystal target that is the radiator of PXR. A beryllium foil is the most prospect candidate of the THz-wave radiator. Since the electron linac of LEBRA was developed for free electron laser (FEL), the electron bunches of 1ps length can be provided by magnetic bunching at the bending magnet section. Thus, very intense CTR can be obtained in the frequency region around 1THz. According to preliminary experiments for CTR production, it is suggested that the most optimized electron beam from the LEBRA linac can provide sufficient photon yield to carry out THz-wave imaging. At present, however, the THz-wave beam emitted from the CTR target can not be transported to the measurement system located at the experiment hall where radiation safety is guaranteed. Thus, we have a plan to alter the PXR beamline for the transport of the THz-wave beam. The new system is expected to allow simultaneous non-destructive imaging in the wavelength regions of THz and X-ray.

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TRANSVERSE BEAM SIZE AND EMITTANCE DIAGNOSTICS USING TRANSITION AND DIFFRACTION RADIATION

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Transverse beam size and emittance monitoring is a crucial task in future linear colliders. Beam diagnostics is required at all stages of the beam production, acceleration and delivery. The diagnostics equipment has to be suitable for electron/positron beams form MeV to TeV energies with resolution form nanometres to hundreds of microns and beam intensities from a fraction to hundreds of nC.

Such a large diversity of the beam parameters implies a diversity of beam diagnostics. The stat-of-the-art in transverse beam diagnostics is the Laser-Wire (LW). This technique is non-invasive, with large dynamic range and high resolution. However, the laser system is expensive and requires a team of qualified people to maintain its conditions.

Optical Transition (OTR) and Diffraction (ODR) Radiation techniques are promising to back LW up. Recent developments have demonstrated that a sub-micrometre resolution can be achieved using the OTR. ODR technique is non-invasive and has demonstrated an ability to measure the beam size as small as 14 um. We have performed a series of experiments in KEK (Japan), CTF3 (CERN) and CesrTA (Cornell University). We have developed a sophisticated simulation code based on ZEMAX software package for optimization of optical systems. The next step is to develop a combined OTR/ODR beam size monitor covering a wide range of beam sizes and intensities.

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SIMULATION OF 2D POINT SPREAD FUNCTION DOMINATED BEAM PROFILE IMAGES BASED ON BACKWARD TRANSITION RADIATION FROM THE TILTED TARGET

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Transverse beam profile diagnostics in electron accelerators is usually based on direct imaging of a beam spot via visible radiation (transition or synchrotron radiation). In this case, the fundamental resolution limit is determined by radiation diffraction in the optical system. A method to achieve a resolution beyond the diffraction limit is to perform point spread function (PSF) dominated imaging, i.e. the recorded image is dominated by the resolution function of a point source (single electron). With knowledge of the PSF, the true image (beam spot) can be reconstructed. In the case of classical backward transition radiation imaging however, the radiation is emitted from the surface of a tilted screen, and a part of the image will be out of focus. While this de-focusing influence can usually be neglected, it was observed already in the case of sub-micron beam size measurements. This paper presents a model to calculate PSF-dominated beam profile images based on backward transition radiation from a tilted screen surface, taking into account the influence of de-focusing.

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MICRON-SCALE VERTICAL BEAM SIZE MEASUREMENTS BASED ON TRANSITION RADIATION IMAGING WITH A SCHWARZSCHILD OBJECTIVE

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Transverse beam profile diagnostics in the case of micron-scale beam sizes from modern electron accelerators is a challenging task. Backward transition radiation (BTR) imaging in the visible spectral region is usually applied but it is close to the diffraction limit, i.e. the measured beam image is dominated by the point-spread function (PSF) [1,2]. In order to improve the resolution and to measure sub-micron beam sizes, the influence of the PSF that depends both on the wavelength and optical aberrations should be decreased [3]. This can be realized by imaging in the EUV region using a multilayer Schwarzschild objective (SchO) which is free of some types of aberrations [4].

A first test experiment devoted to micron-scale beam size measurements has been carried out at the Mainz Microtron MAMI (Germany), using visible BTR and a SchO. This report summarizes first results of PSF dominated imaging with vertical beam sizes in the order of a few microns. Possibilities to extend the use of a SchO in future experiments with EUV BTR will be discussed.

The work was partially supported by the Russian Ministry of Education and Science within the program "Nauka" Grant No. 3.709.2014/K

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EXPERIMENTAL STUDY OF OPTICAL TRANSITION RADIATION INTERFERENCE

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Optical Diffraction Radiation (ODR) is a promising non-destructive transverse beam size diagnostics for future high intensity accelerators. The ODR signal is much less intense than that from the well-known Optical Transition Radiation (OTR), so synchrotron radiation and wake-fields can interfere with the signal, complicating the data analysis. The insertion of a mask upstream of the target allows this undesired background to be reduced but, at the same time, the mask becomes an additional source of light that will interfere with that produced by the target. In order to study this phenomenon a simple OTR interferometer has been installed on the CTF3 CALIFES beam line at CERN. The set-up allows the OTR signal of two screens to be recorded in both an imaging and far-field (angular) configuration. In the imaging configuration the results clearly show a strong correlation between the total light intensity and the distance between the two OTR sources, in good agreement with optical simulations. Both experimental data and simulations show an increasing light intensity for an increasing distance between the sources with a maximum value corresponding to the sum of the intensity of the two sources as predicted by Warstki et al. J.Appl.Phys. 1975. The key parameter for such interference is the formation length $L = (\gamma^2)\lambda/(2\pi)$, where γ is the Lorentz factor and λ the observation wavelength.

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STUDY OF ANGULAR DISTRIBUTION OF QUASIMONOCHROMATIC EUV RADIATION GENERATED BY 5.7 MEV ELECTRONS IN A MO/SI MULTILAYER

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In a number of studies [1-4] it has been theoretically and experimentally shown that at the interaction of a relativistic electron with a periodic structure, a quasimonochromatic component of X-rays is generated in the direction of the Bragg diffraction.

The mechanism of this radiation is similar to the parametric X-ray radiation of relativistic charged particles in crystals. This report presents the results of an experimental study of the angular distribution of EUV radiation generated by 5.7 MeV electrons in a periodical structure of a Mo/Si multilayer. The angular distributions were measured in the diffraction plane and at the angle $\theta_{Dy} = 1/\gamma$ with respect to this plane. The experimental results are compared with the simulation using the theory [2].

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ELECTROMAGNETIC FIELD OF A CHARGE MOVING IN A WAVEGUIDE AND INTERSECTING A BOUNDARY BETWEEN VACUUM AND RESONANCE DISPERSIVE MEDIUM

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Electromagnetic field of a charge that uniformly moves in a circular waveguide with a semi-infinite dielectric possessing frequency dispersion of a resonant type is under consideration. This problem is a generalization of the case of a nondispersive dielectric (considered earlier). The study can be interesting for development of new methods of generation of electromagnetic radiation and acceleration of charged particles. The main attention is paid to the analytical and numerical investigation of the waveguide modes excited by the charge.

We consider two instances in detail: the particle is flying from a vacuum into a resonant medium and, inversely, from the medium into vacuum. In the first case, there is a region where partial compensation of Cherenkov radiation (CR) takes place (as well as in the case of a nondispersive dielectric). However, the electromagnetic field pattern is complex and the role of resonant dispersion is essential. In the second case, CR can penetrate through the boundary, and large Cherenkov-transition radiation (CTR) can be excited in the vacuum region. The conditions for this effect are obtained. It is shown that the CTR can be composed of a single mode (in contrast to the case of nondispersive dielectric, where CTR is multimode).

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ON THE STIMULATED RESONANCE TRANSITION RADIATION OF A BUNCH OF MICRO BUNCHED ELECTRONS

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It is given a brief review of the theory of the stimulated coherent X-ray transition radiation produced in a RTR stack of plates (StRTR) under the influence of accompanying intense monochromatic beams by micro bunched electrons. Though there are tens of publications on the corresponding gain of the amplification of the primary X-ray photons by StRTR, nevertheless, the absence of some important results for new calculation makes to reconsider the existing results and derive the necessary expressions by new methods. Expressions for the gain or total number of photons of StRTR produed by a bunch of micro bunched electrons is derived. The applications of these new results for some experimental possibilities have been discussed.

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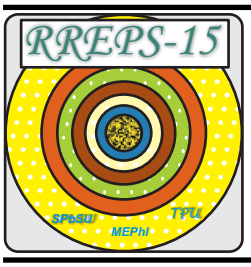

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For Notes

CALCULATION OF PARAMETRIC X-RAY RADIATION DISTRIBUTION FROM A TEXTURED POLYCRYSTAL AND AN APPROACH TO ORIENTATION DISTRIBUTION FUNCTION RECONSTRUCTION

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The parametric X-ray radiation (PXR) by relativistic charged particles in polycrystals was considered in a number of theoretical and experimental investigations during the past two decades. However, in most cases the texture properties of polycrystals was either neglected (uniform distribution of crystallites was assumed) or described semi-qualitatively by preferred orientation and misorientation angle. The actual texture of many promising radiation targets, e.g. nanodiamond films, requires a more extended qualitative description in terms of Orientation Distribution Function (ODF).

In the present contribution we consider spectral and angular distribution of PXR accounting for ODF of the polycrystal. It is shown that at least two texture models result in analytical solutions for the intensity distribution, they are: fiber texture model and peak component texture model.

Using the characteristics of real specimen of polycrystalline nanodiamond film and parameters of existing electron accelerators we make estimations of a number of emitted photons. The numerical comparison of PXR in monocrystals and polycrystals is discussed.

As one of the possible applications, the inverse problem of ODF determination from PXR data is considered. It is proven that under certain assumptions ODF is completely determined through the intensity distribution.

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COHERENT X-RAY RADIATION BY RELATIVISTIC ELECTRON IN A STRUCTURE "AMORPHOUS LAYER- VACUUM-PERIODIC LAYERED MEDIUM"

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The dynamic theory of coherent X-ray radiation by relativistic electron crossing a three-layer structure consisting of an amorphous substance layer, a layer of vacuum and a layer with artificial periodic structure has been developed. The process of radiation and propagation of X-ray waves in an artificial periodic structure have been considered based on two-wave approximation of dynamic diffraction theory in Laue scattering geometry. The expressions describing the DTR and PXR spectral-angular densities and their interference in the considered structure have been obtained for general case of asymmetric reflection of the electron coulomb field from the layer with artificial periodic structure. At that, under constructive interference of TR waves from different boundaries of amorphous layer and constructive interference of TR waves from amorphous layer and entrance boundary of artificial periodic structure the spectral-angular density of DTR can be increased by orders of magnitude greater than the value of the spectral-angular density from artificial structure only. The possibility to increase the angular DTR density with increasing the substance density of amorphous layer has been shown.

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CR/SC MULTILAYER RADIATOR FOR PARAMETRIC EUV RADIATION IN "WATER-WINDOW" RANGE

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Recently, in [1] it was experimentally shown that a Mo/Si multilayer may be used for generation of quasimonochromatic radiation in the range of extreme ultraviolet. This report presents the results of similar experimental study using the multilayer radiator consisted of 100 Cr/Sc bi-layers placed on a 0.5 μm thick Si_3N_4 membrane. The multilayer was specially created for generation of the parametric radiation in the вГЁwater windowвГ№ spectral range of generated photons. The results of test measurements of the angular distributions of the density of extreme ultraviolet radiation generated by 5.7 MeV electrons in a periodic structure of the multilayer are presented and discussed.

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DIFFRACTION AND VAVILOV-CHERENKOV RADIATION AS A NOVEL SOURCE OF THZ RADIATION

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Diffraction and Cherenkov radiation of relativistic electrons from a dielectric target has been proposed as mechanism for production of intense terahertz (THz) radiation in the forward direction. The use of an electron beam of a 4th generation light source appears to be very promising. A moderate power from the electron beam can extracted and converted into THz radiation with nearly 100% efficiency. The initial experiment on THz observation will be performed at CLARA/VELA FEL test facility to demonstrate the principle to a wider community and to develop the radiator prototype. In this poster, we present our theoretical predictions (based on the approach of polarization currents), which provides the basis for interpreting the future experimental measurements. We will also present our hardware design and discuss a plan of future experiment.

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ELECTROMAGNETIC FIELD IN A CIRCULAR WAVEGUIDE WITH THE BOUNDARY BETWEEN A VACUUM AREA AND AN AREA HAVING A CYLINDRICAL DIELECTRIC LAYER

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We consider a mode transformation in the circular waveguide with a vacuum part and a part having cylindrical dielectric layer. The problem is analyzed for axially symmetric mode (propagating or evanescent) falling in two cases: a mode falls from the vacuum part and a mode falls from the partially dielectric part.

Analytical investigation is performed by crosslinking method. In the cases of a narrow channel and a thin dielectric layer, the approximate solution has been constructed. When the channel radius is small the mode with number of incident mode is mainly excited in reflected and transmitted field. For the case of a thin dielectric layer the excitation coefficient of transmitted mode with a number of incident mode tends to unity while all reflected modes are proportional to the first order of small parameter. However, in the case of mode falling from dielectric part the amplitude of the reпæЪected mode with a number of incident mode is of second order of small parameter.

In order to analyze the mode transformation in general case the numerical algorithm has been constructed. Typical behavior of the reflection and transmission coefficients depending on channel radius is obtained. In particular, it can be shown, that the evanescent incident mode can excites propagating modes in reflected and transmitted fields.

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GENERATION OF CHERENKOV RADIATION IN OPTICAL FIBERS BY 6-MEV ELECTRONS. GEOMETRY OF PROPAGATION AND LIGHT DECAY

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Beam loss monitors based on optical fibers are widely used at GeV-scale accelerators [1]. Recently there was proposed to use such a technique for a beam profile diagnostics [2]. We have investigated a feasibility to use the Cherenkov radiation (ChR) generated in a fiber to measure a beam divergence. Measurements were carried out for different angles between a fiber axis and the electron beam and showed a possibility of such kind of diagnostics. The decay of ChR in a fiber with thickness 0.6 mm and length up to 10 m were measured. The proposed technique can be used for low intensity beams (a few pC level).

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GENERATION OF THZ-RADIATION IN THE CHERENKOV DECELERATING STRUCTURE WITH PLANAR GEOMETRY AT FREQUENCY ∼ 0.675 THZ

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As one of the ways THz-radiation can be generated by the relativistic electron bunches travelling through Cherenkov decelerating dielectric filling capillary channel. Sapphire and other dielectric materials for the internal surface coating of the capillary can be used. Relativistic electron bunches having 100 μm in diameter and pulse durations of 1 ps or shorter are capable to produce substantial power of THz-radiation. The aperture of Cherenkov decelerating structure should be comparable with the sub-mm wavelength (0.05-3 mm). Such type of decelerating system allows to provide the wide range of operating parameters at the various geometrical sizes. But it is necessary to consider that such capillaries are difficult in production because there is a requirement to drill a small aperture in a long crystal having high hardness. In this regard it would be desirable to offer transition option from the axial geometry to the planar. Besides ribbon beam have some advantages as more simple focusing at low energies and possesses smaller expansion in the drift space. In this report design and results of electrodynamics study of the decelerating planar dielectric filling Cherenkov channel at frequency 0.675 THz will present. Characteristic's comparison with axial geometry channel will also delivered. A horn antenna attached to such channel at 0.675 THz resonant frequency will considered.

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INFLUENCE OF MULTIPLE SCATTERING OF RELATIVISTIC ELECTRON ON COHERENT X-RAY RADIATION BY ELECTRON BEAM IN A SINGLE CRYSTAL

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Coherent X-ray radiation by a beam of relativistic electrons crossing a single-crystal plate in Bragg scattering geometry have been considered. Initial divergence and multiple scattering of electrons on atoms are taking into account in the present work. In the present work, the initial divergence and multiple scattering of electrons on atoms in the target have been taken into account. The expressions describing spectral-angular characteristic of PXR and DTR have been derived based on the two-wave approximation of diffraction theory taking into account the deviation of electron velocity vector from the electron beam axis direction. The traditional method of cross section averaging over expanding beam of straight electron trajectories are used to account multiple scattering. In the work, the significance (insignificance) conditions of diffracted bremsstrahlung contribution to total yield of the radiation has been estimated. The possibility of dynamic effects manifestation in PXR in the conditions of the electron multiple scattering are shown. The influence of initial divergence of electron beam on the effects of dynamical diffraction manifestation have been investigated. This work was supported by the Ministry of Education and Science of the Russian Federation (project of the state task No.3.500.2014/K in the field of science and state task No. 2014/420).

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PARAMETRIC RADIATION OF ELECTRONS MOVING IN A CRYSTAL ALONG ITS SURFACE

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Motion of charged particles in a crystal is followed by the radiation due to scattering of Coulomb field of the particle on the periodical crystal grating. In X-ray range this radiation called PXR and is well studied both theoretically and experimentally. However, comparative weakness due to absorption of X-rays in target material hampers its practical applications. In article [1] it was proposed and in [2] shown experimentally that PXR becomes considerably more intensive when generated in thin surface layer at grazing incidence of electrons owing to shorter way for radiation in the material.

In this work we propose to use the skimming flight of the charged particles beam over the crystal surface, when part of the beam moves inside the target and the other part is outside. For amorphous target the solution of this problem was reported in [3]. For crystal target it looks to be a promising scheme allowing providing the most possibly long particles trajectories inside the crystal, and simultaneously the shortest way out for the radiation. As the first step for theoretical description in this work we investigate the radiation produced by a charged particle moving under the crystal surface at a fixed distance to it.

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POLARIZATION CHARACTERISTICS OF DIFFRACTION AND CHERENKOV RADIATION FROM A DIELECTRIC SCREEN

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It is well-known that the polarization is one of the most important radiation characteristic as well as intensity and spectrum. In this report we use the "polarization currents" approach [1, 2] to calculate the polarization characteristics (the Stokes parameters) of diffraction and Cherenkov radiation occurring as a result of uniform motion of a charge near a finite size dielectric screen. The Stokes parameters are determined by the geometry of a screen position relative to an electron beam as well as by permittivity of the screen material. Due to these reasons polarization of radiation can have the circular component (can become elliptic one).

The work was partially supported by the program "Nauka" of the Russian Ministry of Education and Science within the Grant No. 3.709.2014/K and the Russian Foundation for Basic Research Grants No. 14-02-31642-mol_a, No. 14-02-01032-A and No. 15-52-50028 YaF_a.

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RADIATION AT CHARGE-EXCHANGE OF IONS

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In the charge-exchange accelerators, negatively charged accelerated ions lose their electrons in a charge-exchange target and become positively charged ions. In the present report, radiation arising at charge-exchange of ions a thin transparent charge-exchange target is considered. It is shown that the spectral and angular distribution of the number of quanta emitted by the hydrogen ion that change its charge from -1 to +1 is described by the formula

$$\frac{dN}{d\Omega d\omega} = \frac{e^2}{\hbar c}\frac{\sin^2\theta}{\pi^2\omega\left(\frac{c}{v}-\cos\theta\right)^2} \tag{1}$$

where dN is the number of quanta with frequency ω emitted in the spectral range $d\omega$ into the solid angle $d\Omega$, $e^2/\hbar c = 1/137$, θ is the observation angle, v is the incident ion velocity. It is interesting that properties of the distribution (1) are independent of the properties of the charge-exchange target if it is thin enough. The applications of such charge-exchange radiation for diagnostics of the charge-exchange process in charge-exchange accelerators are proposed and discussed. Observation of the charge-exchange radiation from the beam of non-relativistic incident ions can be performed by a photon detector installed at observation angle θ close to $\pi/2$, where the distribution (1) has the maximum. The observed frequency range should be out of the spectral peaks of characteristic X-ray radiation of the charge-exchange target atoms.

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SIMULATION OF VARIATION CHARACTERISTICS AT THERMOSTABILISATION OF 27 GHZ BIPERIODICAL ACCELERATING STRUCTURE

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A design of compact accelerating structure with high beam quality is one of the sufficient problems in contemporary X-ray systems development. A compact biperiodical accelerating structure for medical application with operating frequency 27 GHz was proposed to minimize the accelerator size and weight. More careful calculations of variation characteristics are necessary for such wavelength which is 3-10 times lower in comparison with conventional structures of 10 and 3 cm bands. Results of this study will be presented in the report. Also, a combination of high electromagnetic fields and long pulses at a high operating frequency leads to the temperature increase in the structure, thermal deformation and significant change of the resonator characteristics including the operating frequency. Three versions of temperature stabilization system was proposed and results of it's simulations will also discussed.

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SAPPHIRE DECELERATING CAPILLARY CHANNEL INTEGRATED WITH ANTENNA AT FREQUENCY 0.675 THZ

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Nowadays interest to the THz-radiation significantly increased in medicine (THz tomographs), in pharmaceutics (definition of medicament's compositions), in introscopy of large-size objects (ships, trains, containers) and others. THz-radiation can be generated by the relativistic electron bunches passing through Cherenkov decelerating capillary channel (circular waveguide with dielectric filling) with horn extraction. Relativistic electron beams having $\sim 100\mu$m in diameter and pulse durations of 1 ps or lower (as in photoinjectors) are capable to produce substantial power of THz-radiation. High-peak power coherent Cherenkov radiation can be produced by a properly modulated high-brightness electron beam or by a single, high-density bunch having sub-wavelength dimension. The aperture of Cherenkov decelerating structure should be comparable with the sub-mm wavelength (0.1-3 mm). Different dielectric materials for the internal surface coating of the capillary channel of mm-sub-mm cross-section can be used. As it's known frequency of 0.675 THz corresponds to the atmospheric window with the high transparency. In this report results of electrodynamics study of the metallized sapphire decelerating Cherenkov capillary will presented. Horn antenna attached to the metallized sapphire capillary channel at 0.675 THz resonant frequency will consider.

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SMITH-PURCELL RADIATION FROM SURFACE PERIODICAL STRUCTURE FORMED BY THE EXTERNAL PLANE WAVE

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A charged particle moving uniformly near a medium surface is known to be a source of so-called diffraction radiation, if there is a longitudinal (along the velocity vector) momentum transfer from the particle to the medium, so the conservation laws allow the photon emission. Thus, at uniform charge motion, parallel to the surface of the homogeneous isotropic medium, no diffraction radiation arises.

In this work we propose a technic of radiation generation, using nonlinear interaction of a plane electromagnetic wave with the medium, e.g., wave associated with laser field. Strong monochromatic field, which is comparable with intra-atomic field, changes a space-time distribution of the bound charges of the medium, which cannot be considered homogeneous any more. Therefore the scattering of the particles Coulomb field on the periodically inhomogeneous structure formed by the field of the external electromagnetic wave leads to an emergence of Smith-Purcell radiation. We study the dependence of the radiation characteristics on parameters describing the plane wave and the charged particles. The scheme proposed is a mixture of two different non-invasive bunch diagnostics schemes: electro-optic method [1] and based on Smith-Purcell radiation one [2].

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SPATIAL AND TEMPORAL COHERENCE EFFECTS IN PARAMETRIC X-RAY RADIATION

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Coherent emission from an electron bunch moving in magnetic fields is described using the phase shift for each electron in a bunch [1] $\varphi_{SR}^{(i)} = \exp\{i\ \mathbf{k}\ \mathbf{r}_i\}$, where $\mathbf{k}$ is the wave vector, $\mathbf{r}_i = \{x_i, y_i, z_i\}$ is the radius-vector of i-th electron. For such radiation mechanism as parametric X-ray radiation (PXR) for which atom electrons from a crystallographic plane are emission sources the time dependence has to be included into the phase shift:

$$\varphi_{PXR}^{(i)} = \exp\left\{i\left(\mathbf{k}\ \mathbf{r}_{pl}^{(i)} - \omega\ t^{(i)}\right)\right\} \tag{1}$$

Here $\mathbf{r}_{pl}^{(i)}$ is the radius-vector characterizing the point at the plane where i-th electron crosses it, $t^{(i)}$ is the time interval characterizing time of this crossing. The first term in (1) is responsible for spatial coherence, the second one - for temporal. If a crystallographic plane is tilted at the angle θ_B relative to the electron beam propagating along z-axis then we have:

$$\mathbf{r}_{pl}^{(i)} = \{x_i, y_i, x_i/\tan\theta_B\}\,, \omega t^{(i)} = \frac{2\pi}{\beta\lambda}\left(x_i/\tan\theta_B - z_i\right)$$

Influence of both terms on characteristics of coherent PXR produced by microbunched beams is considered in the report.

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THZ CHERENKOV DIFFRACTION RADIATION FROM A TRIANGULAR PRISM

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This work is focused on the studying and the theory developing of a Cherenkov diffraction radiation in the terahertz (THz) frequencies range. The effect of the radiation generation, when a charged particle is flying near a target with different forms and sizes, has been studied by the method of polarization currents. For diffraction radiation this method was applied for the first time in [1], and then it was developed, including THz range [2-5].

In this work much attention is given to studying the radiation arising in a target with the shape of a triangular prism. The triangular shape of the target allows us to bring a radiation under some angles out of a target without refraction at the boundary "medium–vacuum". The expression for the angle and frequency distribution of the radiated energy is obtained and analyzed for different wavelengths and particle energies. The approximate efficiency of such THz source is estimated.

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THZ RADIATION UNDER NONCENTRAL PROPAGATION OF ELECTRONS THROUGH PERIODICAL CHANNEL

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Generation of electromagnetic radiation in the frequency region of terahertz (THz) has attracted ever-growing attention for its fundamental significance and interesting applications. In our previous work [1] we investigated source of THz radiation based on electrons moving through the channel with variable radius, where radiation arises due to Cherenkov (CR) and Smith-Purcell (SPR). It was shown that mechanism of SPR could be used as powerful source of THz radiation.

In order to correct theoretical model and approach experimental conditions at LUCX facility in KEK in Japan , it would be very useful to investigate radiation under noncentral propagation at distance b from axis of corrugated channel. Theoretical model describing noncentral propagation is discussed. Numerical calculations are performed and radiation characteristics, for noncentral case are compared with those for central electrons propagation. Intensity dependence of SPR and CR peaks on distance b is investigated for different target parameters.

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TRANSITION RADIATION OF MULTIPLY CHARGED IONS

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In this paper we solve the problem of the influence of the charge exchange of accelerated multiply charged ions on the characteristics of the transition radiation. Processes capture or loss of electrons leads to the fact that the fields in each of the medium are different ionic currents. Conditions "instant" capture or losses of electrons in the medium allow time to find the appropriate fields from the condition of continuity of the normal and tangential to the interface component. The problem of finding the spectral-angular density of transition radiation ions at the interface of two media (or in thin plates) in a possible capture or loss of electrons is achieved when the traditional way of calculating the flow of the Poynting vector through the remote surface. It is shown that the processes of capture (loss) of electrons by multiply charged ions greatly increase the output of the transition radiation in determining the equilibrium ionic charge in the medium. Physically, this is due to the emergence of an additional contribution of the electrons in the radiation yield, which capture or loses multiply charged ions in the medium. This contribution is similar to the contribution instant start or stop the charges.

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TRANSITION RADIATION FROM MONOLAYER: PHYSICAL AND COMPUTER MODELLING

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A charged particle crossing an interface between two media with different dielectric properties is a source of transition radiation (TR) [1] applied to the detection of super-high energy particles. In our previous paper [2] we investigated the graphene monolayer as the simplest but along with it real example of two-dimensional layer, in order to study TR characteristics. Also, high graphene conductivity could make an important contribution into TR in case of a big number of the layers. In article [2] the problem was solved analytically in a zero approximation with the suggestion that polarization currents are produced directly by the charged particle field. In this work we obtain both analytical and numerical results for a sinusoidal shaped monolayer; the results turn into those for the plane one in the corresponding limiting case. All the results can be applied not only to the graphene, but also to an arbitrary monolayer.

To accomplish the investigation, we compare our results with Computer Simulation Technology modelling (CST), which offers accurate, efficient computational solutions for electromagnetic design and analysis.

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XI International Symposium

"RREPS-15"

Radiation from Relativistic Electrons in Periodic Structures

6-11 September 2015, Saint Petersburg, Russia

Section 4

Diffraction Radiation, Smith-Purcell Effect

For Notes

RECENT STUDIES OF SMITH-PURCEL RADIATION AS LONGITUDINAL BUNCH PROFILE MONITOR

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We report on the recent studies of Smith-Purcell radiation aimed at developing a longitudinal bunch profile monitor. In particular we report on first measurements of the polarization and azimuthal distribution of the radiation. We also report on studies done in the linac of synchrotron SOLEIL to measure the distribution of Smith-Purcell radiation. Using these results we discuss the plan of building a single shot Smith-Purcell radiation monitor.

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CHARACTERISTICS OF SMITH-PURCELL RADIATION IN MILLIMETER AND SUB-MILLIMETER WAVELENGTH REGION

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Investigations of the Smith-Purcell radiation (SPR) were began with non-relativistic electron beams with some unexpected experimental results. Further the experimental investigations were performed with relativistic electron beams for application to beam diagnostics. Large discrepancy between different theoretical models significantly increases the role of experimental studies of this phenomenon. In this report we present some problems and features of experimental investigations of SPR in millimeter and sub-millimeter wavelength region. The problems of prewave zone and coherent effects are considered. The shadowing effect, focusing of radiation using a parabolic SPR target and effect of inclination of target strips were investigated with moderately relativistic electron beam.

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EUV AND X-RAY POLARIZATION RADIATION AS A PERSPECTIVE INSTRUMENT FOR SUBMICRON BEAM DIAGNOSTICS

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Polarization radiation arises when a moving charge acts upon matter by its Coulomb field, and the matter polarized by this dynamically changing field becomes a source of radiation. The charged particle itself can move uniformly and nevertheless generate electromagnetic radiation: widely known Cherenkov and Transition radiations, Diffraction radiation (DR), Smith-Purcell radiation (SPR), Parametric X-ray radiation. Polarization-type interaction of particles with matter can be a good source of electromagnetic radiation, including Free Electron Lasers based on SPR, but is especially useful for beam diagnostics.

In this report we shall discuss basic features of these types of radiation in EUV and X-ray range as a prospective instrument for submicron beam diagnostics. We also discuss the possibility of using X-ray backward TR, PXR from multilayered structures, X-ray CR near the absorption lines, and their distinctive features for attosecond electron bunches. At last, we discuss DR and SPR in EUV/X-ray region: possibility for diagnostics of bunch length with help of coherent radiation and beam size with help of incoherent radiation, including incoherent form-factor. Along with it we also mention what was made in theory and which problems have not been solved yet.

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SIMULATION OF COHERENT DIFFRACTION RADIATION GENERATION BY PICO-SECOND ELECTRON BUNCHES IN AN OPEN RESONATOR

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We have studied theoretically the process of generation and accumulation of coherent diffraction radiation (CDR) produced by short electron bunches in open resonator at LUCX facility of ATF KEK. In contrast with conventional applications of resonators for FELs in our case radiation is generated by electron bunches passing through vacuum holes in both mirrors (1,2).

In this report we compare CDR characteristics in resonator obtained by a) numerical simulation using PIC code KARAT, b) Laguerre-Gaussian modes of resonator and c) simulation of generation and propagation of CDR in an entrance and an exit mirrors using generalized surface current method. Two schemes, namely semi-confocal with mirror radius of curvature 840 mm which was used in experiment (2) and confocal one were investigated. Losses and Q-factor of resonator were calculated. By these results geometric and diffraction losses of CDR in the resonator were calculated and new scheme of experiment was proposed to achieve Q-factor much higher than measured in the experiment (2).

The work was partially supported by the Russian Ministry of Education and Science within the program "Nauka" Grant No. 3.709.2014/K

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FORWARD AND BACKWARD DIFFRACTION RADIATION OF RELATIVISTIC ELECTRONS IN A DIELECTRIC TARGETS

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During the interaction of the relativistic electrons field with a dielectric target various types of electromagnetic radiation, such as Cerenkov radiation, diffraction radiation, transition radiation can be generated. In this report we present the results of experimental studies of the diffraction radiation generated by relativistic electrons in a dielectric target at the interface vacuum-insulator and insulator-conductor in the millimeter wavelength range. The experimental results show that the component of the diffraction radiation of relativistic electrons at the interface insulator-conductor, for any significant refractive index of insulator, is suppressed. The analysis of the results from different points of view was done.

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SMITH-PURSELL EFFECT FROM SPIRAL-SHAPED TARGET

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When a relativistic charged particle moves near the surface, field of the particle excites oscillations of the atomic electrons, so the polarization currents arise, giving birth to the secondary electromagnetic field – polarization radiation (PR). If a charged particle moves with constant velocity along the inhomogeneous medium, PR is called diffraction radiation (DR) [1].

It is of interest to investigate DR from spiral-shaped target, arising when a relativistic charged particle moves along the axis of the spiral. The target has its own periodicity, but it slightly differs from the problem of Smith-Purcell (SP) effect [2], due to helical form of the target, when an element of the target repeats over and over with a free space in between.

The problem is solved in a zero approximation, using polarization currents method [3]. Even this simple approach demonstrates typical SP behavior specific to this kind of problems.

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MEASUREMENT OF POLARIZED COHERENT DIFFRACTION RADIATION FROM A SLIT AND AN EDGE

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Diffraction radiation is emitted when an electron beam passes near an edge or interface between two media with different dielectric constants. Theoretical and experimental investigation of diffraction radiation is performing at several electron accelerator facilities. If the wavelength of the diffraction radiation is longer than a pulse width of electron beam, each radiation is coherently enhanced. Sub-millimeter wavelength, so called terahertz radiation, is enhanced by using the sub-picosecond electron beam. In this presentation, we will focus on a polarization state of coherent diffraction radiation (CDR) in the range of terahertz wavelength. We have measured polarized CDR generated from a rectangular slit and an edge (half plane), which their edges are aligned along the horizontal direction, with a terahertz camera and a wire grid linear polarizer. Ring profile of the CDR generated from the slit was observed. The intensity of vertical polarization was higher than the horizontal polarization. An asymmetrical intensity distribution between two lobes, aligned along the vertically polarized direction, was appeared owing to the pre wave (Fresnel) zone effect when the electron beam did not pass through the center of the slit. On the other hand, a single peak intensity distribution, which main polarization component was vertical, was measured from the edge.

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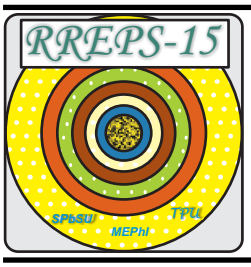

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Section 1

General Aspects of Physical Phenomena and Processes Associated with Electromagnetic Radiation: Day 2

For Notes

RADIATION SOURCES AND THEIR APPLICATIONS FOR BEAM PROFILE DIAGNOSTICS

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Radiation generated by high-energy particle beams is widely used for beam diagnostic purposes. Depending on the mechanism of radiation generation, the emitted wavelength range extends from the THz up to the X-ray region, thus allowing to measure beam profiles in the longitudinal and the transverse plane over a wide range. In this talk, basic considerations for radiation based profile measurements will be discussed with special emphasis on the mechanism of radiation generation and the impact on beam diagnostic measurements.

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HIGH BRIGHTNESS COMPTON X-RAY SOURCE DEVELOPMENT AT KEK

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We have been developing a high brightness X-ray source based on the Inverse Compton scattering (ICS) between an electron beam and a laser pulse stacked in an optical cavity. The X-ray which energy is in the order of 10 keV, have a wide variety of application for material, biological and medical researches. The synchrotron light sources as the several GeV electron ring have been contributing to supply these X-rays. The ICS can deliver these X-rays by using an electron beam of several 10 MeV. The accelerator is expected to be a compact to fit in the university and hospital.

The developments on both of the high intensity electron beam and the high power stacked laser are essential to realize the compact high brightness X-ray source. Two compact electron accelerators in KEK, the Laser Undulator Compact X-ray (LUCX) and the compact Energy Recovery Linac (cERL), are available for the development. The LUCX is a S-band pulse RF accelerator and accelerates an electron beam of 1000 bunches/pulse up to 24 MeV. The cERL is a test accelerator for the energy recovery linac with 1.3 GHz superconducting RF cavities and supplies a "CW" electron beam which suitable to realize the high brightness X-ray source. The development of the ICS X-ray source at cERL has been started in March 2015. We will report the recent activities in LUCX and cERL.

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INTENSE LASER FOCUSED PROFILE MEASUREMENT BY SCANNING ELECTRON BEAM VIA LASER-COMPTON SCATTERING

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Laser-Compton scattering (LCS) is a feasible technique to realize the compact, high brightness X-ray source. The laser photons are scattered by high energy electrons and the energy of the electrons is transferred to the photons. Tightly focus of both laser and electron beam makes it possible to achieve the high brightness X-ray source. The LCS is also a quite useful technique for diagnostics. The laserwire beam size measurement, which laser spot is much smaller than that of electron beam, are well-known. On the other hand, laser focused spot measurement for extremely high peak power laser has not been achieved yet. We proposed to use LCS technique for such a high power laser profile measurement by using very small electron beam, which is an inverse procedure of laserwire that the electron beam size have to be much smaller than that of laser. As a focused electron source, we used a photocathode rf electron gun and very strong solenoid lens. The rf gun can generate very small emittance beam and the beam size of 20μm rms was achieved with the charge of 50 pC/bunch. We have installed an electron beam scanning system and high power CO_2 laser for the demonstration. The principle of laser profile measurement by LCS, recent results of experiments and future prospective will be presented at the conference.

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MUON COOLING BY CHANNELING IN LASER FIELDS

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Channeling effect in crystals is a very convenient method for charged particle bunches manipulation. In particular, this phenomena can be used for charged particle beams shaping, collimation and extraction. As known, considerable radiation energy losses of channeled particles (due to channeling radiation) can be used as a novel method of beam cooling. However, during such interaction of charged particles with crystals inelastic processes take place causing channeled particles to leave channels (dechanneling) and other particles (as a result of nuclear reactions) to be born.

Charged particle beams channeling in laser field has some advantages over crystal channeling due to strong suppression of inelastic processes. Besides, potential channels formed by combined laser fields have a number of features helping to adjust channels structure (depth, width etc). In this work we describe process of muons channeling in laser channels. Radiation losses for charged particles are taken into account and both analytical and numerical descriptions of radiation cooling are presented. Also a comparative analysis for the efficiency of muons cooling by laser and crystal fields is given paying attention to their relative advantages and drawbacks.

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RADIATION FROM RELATIVISTIC ELECTRONS IN "LIGHT UNDULATOR" AND IN CONVENTIONAL UNDULATOR. QUANTUM AND CLASSICAL APPROACHES

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The Thomson scattering of laser photons by a relativistic electron can be considered as radiation in a "light undulator". Classical formulas describing characteristics of the conventional undulator radiation (UR) are applicable for the radiation in a "light undulator" if it is possible to neglect by recoil effect.

In the opposite case the discrete quantum processes of photon emission in each interaction of an electron with laser photons have to be considered in terms of cross-section (the Compton scattering process).

We have showed that quantum and classical approaches give the same results for a conventional undulator that allows to use the stochastic description of UR in a complete analogy with simulation of Compton/Thomson photon sources.

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ON SPACE CHARGE EFFECT AT CHARGED PARTICLES CHANNELING IN LASER FIELDS

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Periodic field structure in the region of two intense laser beams overlapping is capable of trapping charged particles in channeling regime. This phenomenon is called channeling in a lasers field and attracts growing attention of researchers today. The reason for this is the ability to recreate channeling-like conditions in vacuum avoiding particles-matter interaction and decreasing influence of undesired processes at crystal channeling.

The dynamics of charged particles in two lasers field was described previously both for a single particle and for a beam of noninteracting charged particles. However, at some conditions space charge effect has a crucial influence on the beam dynamics, increasing particles transverse energy and hardening channeling conditions. While both analytical description and numerical simulation for channeling in laser fields were presented earlier, to take into account beam space charge effect in numerical simulation becomes an important issue that allows computer simulations for real processes.

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COHERENT LIGHT INDUCED IN OPTICAL FIBERS BY A CHARGED PARTICLE. COMMON CHARACTERISTICS OF SYNCHROTRON RADIATION AND LIGHT ESCAPING A BENT FIBER

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Two phenomena relating light channeled in optical fibers and radiation by moving particles are considered: the first one is light induced by a charged particle in optical fibers (PIGL). We review the basic mechanism, the intensity formula, the spectral and polarization properties and the possible application to beam diagnostic. The second one is a similarity between synchrotron radiation and light leaking from a bent fiber. The similarity concerns the tunneling mechanism by which the photon migrates from the particle trajectory – or the fiber – to the "light cylinder", the angular distribution and the impact parameter profile. The latter possesses the typical Airy fringes of a caustic.

The relation between the minimum impact parameter of synchrotron radiation, the electron "side-slipping" and the Schott term of radiation damping theory is reviewed.

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COHERENT RADIATION OF RELATIVISTIC ELECTRONS IN DIELECTRIC FIBERS FOR THE BEAM DIAGNOSTICS

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Dielectric fibers are widely used in technique for light transport. The ability to use a radiation of relativistic electrons in optical fibers in beam diagnostics was proposed recently [1]. The authors propose a method of measuring the transverse profile of electron beams using a fiber optic array. When an electron propagation through the core of a fiber emits Cherenkov radiation at an angle θ_{Ch}, determined by $\cos\theta_{\mathrm{Ch}} = 1/n\beta$, where n is the index of refraction on and along the fiber axis. In the article [2] the theoretical analysis of contribution for different types of polarization radiation in optical fibers was presented. In this report, we present the results of the experimental investigations of coherent radiation properties in the fibers from dielectric materials for different fiber position relative to an electron beam. The experimental results show that we can use fibers for noninvasive beam position monitoring.

The work was partially supported by the Russian Foundation for Basic Research Grant No. 14-02-31642-mol_a.

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COHERENT RADIATION OF RELATIVISTIC ELECTRONS IN A WIRE METAMATERIAL

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We present in this work the experimental investigation of the interaction of relativistic electron field with wire metamaterial. The measurements of the spectral-angular characteristics of coherent radiation were done in millimeter wavelength region (10-40 mm) in far-field zone on relativistic electron beam with energy of 6.2 MeV. Used target represent the right triangular prism that consist of periodic placed copper wires. We showed that bunched electron beam passing near wire metamaterial prism generates coherent Cherenkov radiation. Spectral-angular characteristics of radiation from the wire target were compared with the characteristics of Cherenkov radiation generated in similar experimental conditions in a dielectric target (Teflon prism) that has the same form and sizes.

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OBSERVATION OF CHERENKOV EFFECT NEAR L- ABSORBTION EDGE OF AL

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According to theoretical estimates (e.g., [1]), due to a jump of the dielectric permittivity of Al near the L edge of photon absorption ($E = 72.6$ eV) the Cherenkov radiation (CR) must be observed at the angles $\theta = 10^\circ - 15^\circ$ relative to the electron path. This report presents the results of experimental study of the angular density of extreme ultraviolet (EUV) radiation generated by 5.7 MeV electrons from a 9 μm thick Al foil in forward direction. The angular distributions of EUV radiation were examined using a multilayer Mo/Si mirror located in the cone of CR. For a crosscheck the spectral properties of the radiation measured from the Al foil were compared with the properties of the radiation from a Mylar foil, for which the CR in the EUV range should not be observed. The angular distributions of EUV radiation reflected by the Mo/Si mirror were measured for several angles inside the radiation cone. The comparison of the experimental results and calculations has shown that the CR with photon energy near the L edge of absorption in Al was observed for the first time in this experiment.

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THE SYNCHROTRON RADIATION OF THE TRANSVERSAL OSCILLATOR

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As an application of general results of the radiation for a charge moving around a dielectric cylinder along a helical trajectory the projection of which on the plane perpendicular to the cylinder axis is an arbitrary closed curve, we study the radiation intensity of the transversal oscillation of rotating charged particle. We analyse the influence of the trajectory shift from the circular one on the characteristics of the radiation intensity.

Recently in this frame we have investigated the radiation intensity of a charged longitudinal oscillator moving along a helical trajectory around a dielectric cylinder. Similar to the case of coaxial circular motion under certain conditions for the parameters of the trajectory and dielectric cylinder strong narrow peaks appear in the angular distribution of the radiation intensity in the exterior medium. Instead of a single peak in the case of a uniform coaxial circular motion, for a longitudinal oscillator set of peaks appear. The increase of the oscillating amplitude leads to the increase of the number of the peaks and the peaks are shifted to the direction of small angles.

It is found out that for transversal oscillator one can get same results.

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Section 8

Workshop on THz Radiation Generation

For Notes

PROGRESS TOWARDS COMPACT PRE-BUNCHED FEL REALIZATION

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The motivation for developing linac-based THz source is coming from the growing interest to THz radiation. High gradient photo-cathode RF gun and few tens of femtosecond laser system are used to generate a pre-bunched electron beam. We have proposed two approaches to produce the intense radiation beams in the range of 0.1-5 THz based on Coherent Smith-Purcell Radiation (CSPR) and Coherent Undulator Radiation (CUR) in "super-radiant" regime on 8 MeV and 30 MeV electron beam at KEK LUCX accelerator, respectively. CSPR is generated when a charged particle moves in the vicinity of a periodical pattern or grating. The grating type and period can be chosen to make quasi-monochromatic CSPR spectrum. When radiation wavelength is comparable to or longer than the bunch length it becomes coherent and even more it enters a "super-radiant" regime if micro-bunch spacing became comparable with radiation wavelength and comparable to the grating period. Similar radiation enhancement can be obtained when micro-bunch period coincided with undulator period. In this report the status of experiment, comb electron beam generation, CSPR and CUR achievable characteristics will be discussed.

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TERAHERTZ SOURCE UTILIZING RESONANT COHERENT DIFFRACTION RADIATION AT KEK ERL TEST ACCELERATOR

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An energy recovery linac test accelerator, cERL, has been developing at KEK.It can produce a high repetition rate short bunched electron beam in a continuous operation mode. We propose to develop a high power THz radiation source at the return loop of the cERL. Coherent diffraction radiation of THz regime is emitted when an electron bunch passes through a conductive mirror with a beam hole at the center. If we form an optical cavity using two mirrors facing each other and the cavity length coincides with the bunch repetition rate, the coherent diffraction radiation of multiple bunches adds up coherently in the cavity. By extracting the power through transmission of one of the mirrors, we can realize a high power and high efficiency THz source. We discuss performance of the source assuming the beam parameters of cERL.

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COHERENT RADIATION MEASUREMENTS STATIONS AT KEK LUCX FACILITY

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Recent years have shown the significant progress in the field of application of short and hight brightness THz-frequency pulses. One way to obtain THz radiation pulses is use of coherent radiation generated by femtosecond electron bunches in a compact accelerator. To increase investigation efficiency of various mechanisms for generating EM radiation including stimulated coherent diffraction radiation, Cherenkov radiation, Smith-Purcell radiation, an international collaboration network with leading Universities of Japan and Europe was founded on the base of KEK. As a part of THz program the radiation measurements station was designed and installed at KEK LUCX (Laser Undulator Compton X-ray) facility.

In this report we discuss the detailed design concept and initial test of the radiation measurements station. We present the first results on the measurements of angular distribution and spectrum of a coherent transition radiation.

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GENERATION OF THZ SMITH-PURCELL RADIATION ON FEMTOSECOND ELECTRON BEAM

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Development of compact, tunable, and high power THz radiation sources is an important task in the field of THz science [1]. Short, hundreds of femtoseconds duration electron bunches may produce coherent THz radiation, by means of Smith-Purcell radiation (SPR) in super – radiant regime [2], occuring when a micro-bunched electron beam travels in the vicinity of a periodic target.

LUCX accelerator at High Energy Accelerator Research Organisation (KEK) produces short, hundreds of femtoseconds duration electron micro-bunches with variable repetition frequency, allowing to generate tunable SPR. Echelle profile gratings were designed to generate 500, 750 and 1000 GHz radiation at the first diffraction order. In this status report we will present simulations of spectral response of the gratings as well as angular distributions of SPR using Computer Simulation Technology Particle Studio software. Checks of manufacturing accuracy using laser scanning microscope and dependencies of the radiation yield on the beam impact parameter will be shown. Angular dependencies of SPR will also be discussed.

References

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MICRO-BUNCH INSTABILITIES AS A SOURCE OF COHERENT THZ RADIATION

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Schottky barrier diodes (SBD) are known for their low noise, ultra-fast response and excellent sensitivity. They are often implemented as detectors in the millimetre wavelength regime. Micro-bunch instabilities (MBI) have been detected at many lights sources around the world including the Diamond Light Source, UK. These MBI can result in bursts of coherent synchrotron radiation (CSR) with millimetre wavelengths. More research needs to be carried out with regards to the dynamics of MBI in order to confirm the simulations and to eventually harness the power of the CSR bursts. A single shot spectrometer has been designed and is under operation at the Diamond Light Source. It is composed of eight SBDs ranging from 33-1000 GHz. Unlike previous measurements carried out, each of the SBDs have been individually characterised thus making the results obtained comparable to simulations. In this paper, we present the assessment of each SBD in the spectrometer and the first results of the spectrometer's use in the beam.

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PIC CODE KARAT SIMULATION OF THE NARROW-BAND SUPER-RADIANT THZ SMITH-PURCELL RADIATION GENERATION

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Numerical simulation of narrow-band THz source based on coherent Smith-Purcell radiation (CSPR) generated by a train of microbunches was carried out using particle-in cell code KARAT [1]. The simulation was carried out for beam parameters of LUCX facility (KEK, Tsukuba, Japan) namely beam energy – 10 MeV, microbunch length – 330 fs, microbunch repetition rate – 1 THz, transverse bunch size – 300 microns, impact-parameter (from the center of the bunch) – 300 microns. Two types of diffraction gratings with a period equal to 292 microns were investigated that included the echelette grating and sinusoidal grating. The comparison of angular distributions, intensity and spectral characteristics of the gratings was carried out both for a single microbunch and for a sequence of microbunches. The optimal grating profile that allows to generate intense narrow-band CSPR in the THz region in the transverse direction were defined.

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CORRUGATED CAPILLARY AS THZ CHERENKOV SMITH-PURCELL RADIATOR

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In the past decade accelerator based sources of THz radiation have seen progress in generation of short femtosecond duration electron bunches as well as in THz radiators development. Capillary structures capable of producing powerful Cherenkov radiation wakefields have been used for THz radiation generation [1] as well as for energy modulation in electron beams [2]. Introduction of the corrugation into the Cherenkov based capillary structure for THz radiation generation increases the device tunability due to the mechanism of Smith-Purcell radiation (SPR) [3].

LUCX accelerator at High Energy Accelerator Research Organisation (KEK) produces short, hundreds of femtoseconds duration electron micro-bunches with variable repetition frequency, allowing to generate tunable SPR. Corrugated and non-corrugated capillaries manufactured as sets of dielectric cylindrical rings, together with holders and radiation reflectors, are now ready for experimental study. Simulations of the spectral response for geometries with and without corrugation as well as influence of the radiation reflector on radiation directivity pattern will be discussed. Checks of manufacturing accuracy, performed using laser scanning microscope, will be presented as well.

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THE SOURCE OF THZ RADIATION BASED ON DIELECTRIC WAVEGUIDE EXCITED BY SEQUENCE OF ELECTRON BUNCHES

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We present new method of THz Cherenkov radiation excited in dielectric waveguide by relativistic electron bunches. The sequence of bunches generates monochromatic radiation. The frequency of radiation is defined by the distance separation between the bunches. The studies were carried by using the original updated BBU-3000 code which permits to take into account additional options: quadrupole focusing system, group velocity, dielectric material attenuation. With this paper, we present our algorithm for optimizing the number of bunches and its positions in sequence for generation of narrow band high power Cherenkov THz radiation.

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ELECTRON BUNCH LENGTH DIAGNOSTICS FOR THE LUCX FACILITY BASED ON THE COHERENT OFF-AXIS UNDULATOR RADIATION

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In the nearest future the 30 cm compact edge-focusing wiggler [1] will be installed on the LUCX accelerator facility in KEK (Japan). The parameters of this wiggler (K $\sim$ 0.5...2.4, period length is 6 cm) are such that fundamental radiation frequency ω_{10} is equal to 4.16 THz (0.45 mm) for K maximum value with electron energy about 8 MeV. The rms bunch length expected on the LUCX is around 30 μm, and due to this reason the undulator radiation (UR) will be coherent. In paper [2] there was suggested to use coherent off-axis UR to measure electron bunch lengths. We developed the proposed technique to analyze the possibility of using it for diagnostics applications on LUCX facility. This approach is based on the UR energy registration for the fixed observation angles. The simulated spectra are presented for different observation angles allowing to calculate UR energy for the chosen bandwidth. Both polarization components of UR were also simulated and a possibility of polarization measurements for diagnostics aims is discussed.

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The Authors Index