Backward Transition Radiation in EUV-region as a possible tool for beam diagnostics

L.G. Sukhikh, S.Yu. Gogolev, A.P. Potylitsyn
Tomsk Polytechnic University, Lenin avenue, 30, Tomsk, 634050, Russia
E-mail: Sukhikh@interact.phtd.tpu.ru

Abstract. In this paper we discuss the possibility of proof-of-principle experiment to observe backward transition radiation in EUV region as a first step for beam diagnostics. We have carried out simulations of backward transition radiation angular distributions in the EUV region for molybdenum target for different geometries. The simulation results are promising for beam diagnostics purposes.

Transition radiation (TR) appearing when a charged particle crosses a vacuum-metal interface have a very broad spectrum of applications, for example, for electron beam diagnostics. Nowadays, transverse beam profile monitors based on backward TR (BTR) in optical region are widely used in modern accelerators. Simple and reliable construction and a possibility of single-shot measurements should be mentioned as the great advantages of this technique. However, the use of BTR in optical region has some principle physical limitations which restrict applications at modern accelerators.

The first limitation is the spatial resolution of an optical system that is proportional to BTR wavelength \( \lambda \). The best BTR monitor resolution obtained in the experiment is equal to \( \sigma = 2 \mu m \) for optical wavelengths \([1]\). Such resolution do not allow to measure profiles of submicron beams of such accelerator as KEK-ATF2 \([2]\) with a proper accuracy.

The second limitation is connected with so-called “pre-wave” zone effect \([3]\). This effect causes the broadening of the BTR radiation cone from the well known \( \gamma^{-1} \) value if the detector is situated closer than the \( \gamma^2 \lambda \) distance (\( \gamma \) is the Lorentz-factor). If the detector is set up closer the broadening of the radiation cone may cause the waste of useful information in the optical path.

The third limitation is connected with the coherent radiation. One knows, that the radiation is coherent when a bunch length is comparable with the radiation wavelength. It seems, that it is not a problem because it is almost impossible to obtain the bunch with longitudinal length comparable with optical wavelength but indeed some accelerator instabilities may create some bunch microstructure of such size. It is a big problem for modern X-ray Free Electron Lasers as it was shown at LCLS in recent paper \([4]\). These microstructures that may vary from shot to shot making it impossible to measure the bunch transverse profile. In the European X-FEL project the optical BTR was planned to be used as a main tool for bunch transverse profile measurement. But the recent LCLS results shows that there may be real problems in optical region. The vacuum chambers for European X-FEL were designed for 22.5 deg geometry that makes one to try to use them to use money sparingly.
Taking into account all mentioned above problems with use of optical BTR for the bunch profile measurement one needs some simple method to solve all problems. We propose to use BTR in EUV region ($\lambda \approx 13.5$ nm) as a tool for beam profiles measurement. Even a simple estimation shows that the change of the radiation wavelength from 550 nm to 13.5 nm allows to improve the resolution at approximately 40 times. The pre-wave zone for such wavelength is equal to 84 mm ($\gamma = 2500$, $\lambda = 13.5$ nm) that is not significant. The size of microstructure should also be 40 times smaller to radiate coherently.

Some preliminary simulations were presented in TIPP09 Conference and will be published in [5]. In this paper we present the plan of proof-of-principle experiment that is planned to be carry out in the electron beam of Mainz microtron MAMI.

The MAMI electron beam has energy of 855 MeV and the beam size (rms) may be varied in a wide range from tens of microns to millimeters. We plan to use the setup that was previously used for PXR measurements and have several outputs at different angles and vacuum goniometer. The scheme of the planned setup is shown in Fig. 1.

Two targets will be installed at the target holder in goniometer. The first target is planned to be an “optical” one and the second — the “EUV” one. The target material is the main problem. The target material should have high BTR production efficiency and a long lifetime under intensive electron beam. The latter may be achieved if one uses the silicon metal-coated target. For example, a target that was 300 $\mu$m Si coated by 2 $\mu$m gold was successfully used in KEK-ATF OTR experiments with no damage under intensive electron beam with micron dimensions [6]. As the “optical” target the aluminum one may be chosen because the reflectivity is of about 95%, as the “EUV” target — the molybdenum one. The latter has the best reflectivity in the 80–90 eV region [7]. The molybdenum reflectivity in the spectral region under consideration is shown in Fig. 2. The radiation from a target will be reflected by the mirror $M$ that is planned to be used to better the background conditions. The filter wheel will allow to choose the spectral region that will be detected by the CCD-camera that is planned to be Andor DO 434 BN. The camera is sensitive in a wide spectral range and have the efficiency in 80–90 eV region of about 40%. The angular acceptance of the vacuum tract should be larger then $4\gamma^{-1} = 2.4$ mrad in order to loose no information. The size of the sensitive area of the CCD-camera ($13.3 \times 13.3$ mm$^2$) allows to install it on a distance of 2 m from the target. The whole tract from the target to the detector should be the vacuum one.

We plan to compare the angular distributions of BTR and the integral photon yield of both targets and theoretical simulation results. We also plan to investigate the background conditions for EUV region.

For our simulations we used the well-known model [8]. It is possible to use the BTR model for
the infinite target because the planned target will have the dimensions of $10 \times 10 \text{mm}^2$ (projection on the beam direction) while the effective beam field size is of about $\gamma \lambda$ that for EUV region is equal to 30 $\mu$m. In our simulations we are interested in the radiation in photon energy region from 30 to 150 eV. All simulations have been carried out for an electron with $\gamma = 1675$ Lorentz-factor and infinite flat target. The reflection coefficients for most materials rapidly decrease in the EUV region with the photon energy increase as one may see in Fig. 2. That is why one should install the target at small grazing angle. We have carried out our simulations for target orientation angles $\phi = 10 \text{deg}$, $\phi = 16.75 \text{deg}$ and $\phi = 22.5 \text{deg}$. The first angle is as an example, second one is planned for our proof-of-principle experiment and the third one is very convenient for practical use in European X-FEL project.

Figure 3 shows the angular distribution for the mentioned above target orientation angles for spectral region 30 ÷ 150 eV. The upper energy limit was chosen because the molybdenum reflectivity is almost zero after this value. The lower integration limit was chosen because we plan to use thin filter to block optical and UV parts of BTR. From Fig. 3 one may see that the number of photons decreases rapidly with increase of orientation angle. The central figure 3 shows the angular density of radiation photons that are expected in our experiment.

Figure 3. The angular distribution of BTR from Mo target for different orientation angles integrated over spectral region 30 ÷ 150 eV
5 ÷ 8 eV. That is why we also simulated the angular distributions of BTR in spectral region of 80 ± 3 eV. The latter are shown in Fig. 4. One may see from this figure, that the angular photon density is much smaller that for previous spectral region. However, the decrease of the angular photon density is not so fast and if we will be able to obtain the image of the beam in the second stage of our proof-of-principle experiment for 16.75 deg geometry we may hope that the technique will also be efficient for European X-FEL project.

The BTR angular distribution shown in Figs. 3 and 4 allows confident identifying of the radiation process in the experiment. The form of the measured distributions will allow to estimate the background conditions for future diagnostics. The photon yield for 16.75 deg geometry and spectral region 30 ÷ 150 eV is equal to $4.73 \cdot 10^{-3}$ per electron that gives for MAMI current (100 μA) $3 \cdot 10^{12}$ ph/sec. For spectral region of 80 ± 3 eV one may obtain in 22.5 deg geometry the photon yield $3.6 \cdot 10^{-4}$. For the typical bunch population ($5 \cdot 10^9$ electrons/bunch) this value gives $1.8 \cdot 10^6$ ph/bunch that seems to be enough to carry out single shot measurements of the bunch transverse profiles in European X-FEL project.

Finally, we can say that the EUV BTR seems to be a promising tool for a single shot high resolution diagnostics of electron beam profiles. The estimations carried out using well known models show the possibility of such diagnostics. The simulations carried out for 22.5 deg geometry shows that in principle it may be possible to use European X-FEL vacuum chambers with new filling to use money sparingly. Now we hope that the proof-of-principle experiment will be successful and will prove our simulations.

Reference

[1] M. Ross et al., SLAC-Pub-9280, (2002).
[2] ATF2 Group, ATF2 Proposal, 1, (2006).
[3] V. A. Verziolov, Phys. Lett. A 273 (2000) 135.
[4] H. Loos et al., SLAC-PUB-13395, (2008).
[5] L.G. Sukhikh, S.Yu. Gogolev, A.P. Potylitsyn, NIMA, to be published.
[6] P. Karataev, PhD thesis, Tokyo Metropolitan University, 2004.
[7] Henke B. L., Gullikson E. M. and Davis J. C., Atomic Data and Nuclear Data Tables 54(2) (1993) 181
[8] V.E. Pafomov, Trudy Fiz. Inst. Akademii Nauk USSR XLIV (1969) 28 [Proc. P.N. Lebedev Phys. Inst. 44 (1971) 25].