Observation of Quasi-monochromatic EUV Radiation Generated by 5.7 MeV Electrons in Periodic Structure of Multilayer Mo/Si Mirror

S.R. Uglov, V.V.Kaplin, L.G.Sukhikh, A.V.Vukolov

Tomsk Polytechnic University (TPU), Tomsk, Russia

e-mail: uglov@tpu.ru

CHANNELING 2014
CHARGED & NEUTRAL PARTICLES CHANNELING PHENOMENA
Capri (Napoli), Italy, October 5 - 10, 2014
ISTITUTO NAZIONALE DI FISICA NUCLEARE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Abstract

The angular distributions of extreme ultraviolet (EUV) radiation with a photon energy of about 70 eV measured for several values of the angle of incidence of the 5.7 MeV electrons on the surface of a multilayer mirror have been investigated. It is experimentally shown that the EUV radiation emitted in the direction of backward transition radiation has quasi-monochromatic component associated with the coherent radiation generated in the periodic Mo/Si nanostructure of the mirror.

Introduction

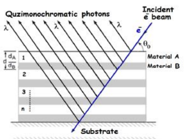

Fig.1.

In a number of papers [1-5] it was shown that artificial periodic structures (APS), as well as crystals, are suitable to generate tunable quasi-monochromatic X-rays by relativistic electrons. There are two radiation processes, diffracted transition radiation (DTR) and parametric X-ray radiation (PXR), which are generated if the APS (also known as multilayer X-ray mirror) is placed under Bragg condition. The energy of the emited photons lies in a narrow spectral range which is determined by the Bragg diffraction law. The mechanism of radiation generation in multilayer X-ray mirrors (MXM) is similar to the mechanisms of PXR and DTR generation from periodic crystal structures. Experiments [3-5] have been carried out for MXM in the X-ray region with photon energies of E_{ph}= 6-15keV.

Recently, experimental investigations in order to detect radiation connected with periodic structure of the target (periodic structure radiation, PSR) in the EUV region have been started at the Tomsk Polytechnic University, using a 5.7 MeV electron beam [6-8]. More promising result has been observed in [8]. Measurements of angular distributions were carried out for a Bragg angle $\theta_o = 67.5^o$ by scanning the detector angle θ_D around the angle $2\theta_o = 135^o$. For these parameters and assuming d = 113.2 Å and $\theta_D = 135^o$ radiation with a photon energy of E_{ph} = 60 eV should be generated. The comparison of the angular distribution of EUV radiation from a multilayer Mo/Si radiator and the angular distribution of EUV radiation from a molybdenum monolayer radiator has shown the additional EUV contribution from multilayer radiator (see Figure 2). This fact was linked to the observation of PSR contribution. However, experimentally observed increase in the intensity integrated over the spectrum is not direct evidence of observing the PSR effect. A trustworthy proof of PSR generation fact is observation of one of its fundamental properties, namely the dependence of the energy of generated photons E_{ph} on kinematic parameters of interaction process, such as the angle of electrons interaction with the surface of the target θ_o and of radiation coming out of the

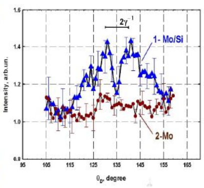

Fig.2.

Angular distribution and quasi-monochramatic properties

As example, let's consider the dynamics of changing the angular distribution and spectrum of DTR component of radiation with changing the value of Bragg angle θ_o, using the theory [3, 4].

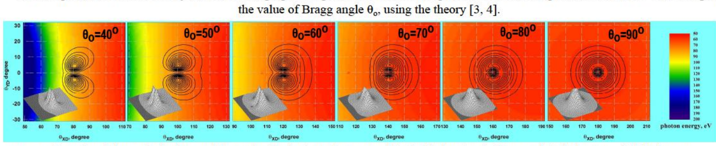

Fig.3. Dynamics of changes in the shapes of the angular distribution and spectrum of DTR with changing the Bragg angle θ_o in the range of 40-90 degrees. Colors show the changing of photon energy in radiation cone. Structure period d = 113.2 A, the number of Mo/Si bi-layers - 50, electron energy - 5.7 MeV.

The spectral composition of the radiation will be tested using the effect of anomalous photon absorption near L edge of Al (E_L =

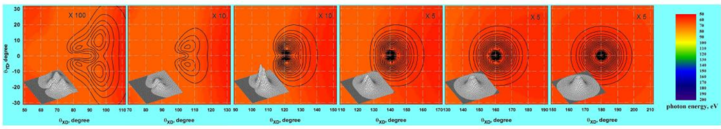

Fig.4. Dynamics of changing the angular distribution and spectrum of radiation passed through Al filter with the thickness t = 1 μm (Al) + 0.015 μm

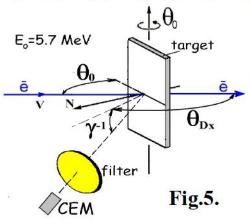

Fig.5.

Geometry of investigation of spectral-angular properties of radiation.

In order to simplify the interpretation of experimental results, it is better to investigate the angular distribution of the radiation generated at an angle $\theta_{Dy} = 1/\gamma$ to the plane VN ($1/\gamma = 5.1^0$).

The actual range of searching the influence of photon absorption near the L edge of Al on angular distribution of quasi-monochromatic component of radiation is $40^0 < \theta_0 < 60^0$.

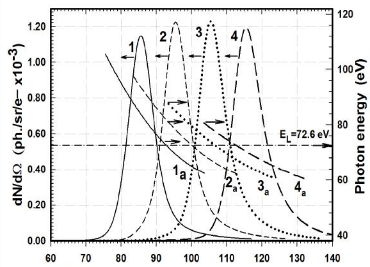

Fig.6. Angle θ_{Dx}, degree

Curves 1-4 show the angular distributions of DTR emitted at an angle $\theta_{DY}=1/\gamma$ to the plane VN.
Curves 1a - 4a show the dependence of the energy of photons at the peak of DTR spectrum from the value θ_{DX}.
Curves 1-4 and curves 1a- 4a are calculated for θ_o = 42.5°, 47.5°, 52.5° and 57.5°, respectively.

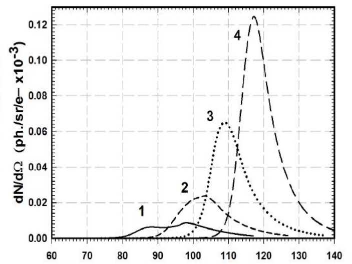

Fig.7. Angle θ_{Dx} (degree)

Curves 1, 2, 3 and 4 show the angular distributions of DTR with taken into account the absorption of radiation by 1μm aluminum filter.

Experimental setup and results

Search of parametric radiation from X-Ray mirror
Experimental setup based on microtron M-5

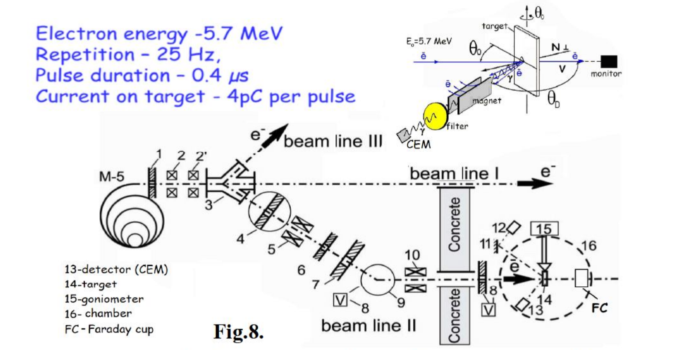

Fig.8.

Figure 9 shows the measured angular distributions (curve 1-5) of the EUV radiation, emitted from Mo/Si multilayer (curve 1-5) and from 200μm Si wafer (curve 6-7) at the angle of 1/γ with respect to the plane **VN**, after passing through 1 micrometer Al filter. Curves 1 - 5 were obtained when θ_o = 40°, 45°, 50°, 52.5°, and 57.5°, respectively. Curves 6 and 7 were obtained when θ_o = 45° and 57.5°, respectively. Curves 6 and 7 presented in Figure 9 for comparison in order to show that the radiation generated in Si wafer is absorbed in the Al filter stronger than that generated in MXM. As can be seen from Figure 10, which shows the results presented in Figure 9 but after subtraction of the background substrate, there is an overall increase in the intensity of the detected radiation with increasing θo. Position of the maxima of angular distribution shifted toward higher values of θ_D, and the value of displacement $\Delta\theta_D$ strive to $\Delta\theta_D = 0°$ with increasing angle θ_o. The general tendency of change of the experimental angular distributions coincides with the tendency of the change of the calculation angular distributions of DTR (see Figure 7). It proves the quasi-monochromaticity of radiation measured in the experiment.

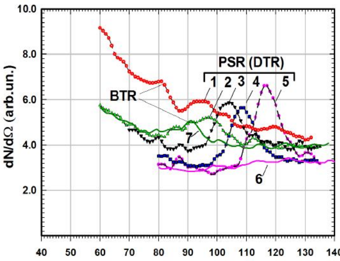

Fig.9. Angle θ_{Dx}, (degree)

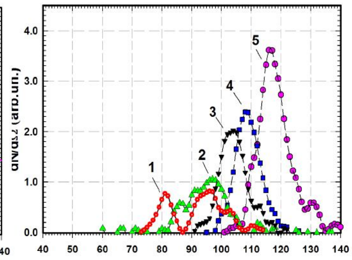

Fig.10. Angle θ_{Dx} (degree)

Detailed consideration of the angular distributions shows that the angular distributions, additionally to DTR peaks, may also have peaks corresponding the weakened backward transition radiation (BTR). For example, for θ_o = 40°, the first peak on the curve 1 corresponds to BTR weakened by Al filter (with a maximum at θ_D = 80°), and the second peak (shifted relative to the position of specular reflection) is the part of PSR with the photon energies that are less than E_L = 72.6 eV. Comparison of curves 2 and 7 in Figure 9 also shows the simultaneous observation of BTR and PSR contributions in the case of curve 2. The comparison of curves 6 and 7 shows that the BTR contribution decreases sharply with increasing the angle θ_o.

Estimation of the angular density of the radiation at the maximum of the angular distribution for θ_o=57.5° gives the value of $1.36x10^{-3}$ photons/sr/electron. The resulting value of the angular density of radiation differs from the calculated value (Figure 6, curve 4) on the ~15 %.

Summary

The experimental investigation of the EUV radiation generated by a beam of relativistic electrons in the multilayer oriented near the direction of the Bragg reflection has shown that the EUV spectrum contains additional quasi-monochromatic component. The energies of photons of this component of radiation are concentrated near the energy value determined by the law of Bragg diffraction. Calculations using a dynamic model of the radiation generation [3,4] are in good agreement with the experimental results.

Since the spectral composition of the generated radiation can be controlled by changing the angles of the target orientation θ_0 and/ or detector position θ_D, then the results are as experimental evidence of the possibility of creating a EUV source with tunable photon energy on the base of the fast electron beam and multilayer mirror. In addition, the observed effect of generation of quasi-monochromatic EUV radiation can be used for the development on this basis of new methods of diagnostics and measurement of submicron transverse dimensions of the electron beams in modern accelerators [9].

References

1. Andre J.-M., Pardo B., and Bonnelle1 C. // Phys. Rev. – 1999. – E 99. – P. 968.
2. Kaplin V. V., Uglov S. R., Zabaev V. N., Piestrup M. A., Gary C. K., Nasonov N. N., and.. Fuller M. K., Appl. Phys. Lett. 76, 3647,2000.
3. Nasonov N., Kaplin V., Uglov S., Piestrup M., Gary C. // Phys. Rev. – 2003. – E 68. – P. 036504.
4. Nasonov N., Kaplin V, Uglov S., Zabaev V.N, Piestrup M., Gary C.//Nucl. Instrum. and Meth. B. – 2005. – V. 227. – P. 41.
5. Kaplin V.V., Uglov S.R., Sohoreva V.V., et al. // Nucl. Instrum. and Meth. B. – 2009. – V. 276. – P. 777.
6. Uglov S.R., Zabaev V.N., Kaplin V.V., Kuznetsov S.I. // Jour. of Phys.: Conf. Ser. – 2012. – V. 357. – P. 012012.
7. Uglov S.R., Zabaev V.N., Kaplin V.V., // Nucl. Instrum. and Meth. B. – 2013. – V. 309. – P. 79.
8. Uglov S.R., Kaplin V.V., Potylitsyn A.P.,Sukhikh L.G.,Vukolov A.V. and Kube G.. // Jour. of Phys.: Conf. Ser.517 (2014) 012009.
9. Sukhikh L.G., Krambrich D., G. Kube, W. Lauth, Yu.A. Popov, and A.P. Potylitsyn, in Proc. DIPAC '11, WEOA02, Hamburg, Germany, p.544, 2011.

The present research was partially supported by the state order of the Ministry of Education and Science No 2456 and Russian Fund for Basic Research, project No 14-02-01032.