EUV RADIATION GENERATED BY 5.7 MeV ELECTRON BEAM IN MULTILAYER PERIODICAL STRUCTURE*

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Abstract

This paper summarizes experimental results of a study of radiation in the vacuum ultraviolet and extreme ultraviolet spectral region, generated by 5.7 MeV electrons in a multilayer mirror target with 50 Mo/Si bilayers. The angular distribution of the radiation generated in the rear hemisphere from the target input surface was investigated. The contribution to the radiation yield caused by the periodic structure of the multilayer target was experimentally studied.

INTRODUCTION

In a number of papers [1-6] 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 radiation photons is emitted in a narrow spectral range which is determined by the Bragg diffraction from a periodic structure.

Transition radiation (TR) emitted in the EUV-region is of particular interest for transverse beam profile diagnostics because its application reduces the contribution of the fundamental diffraction limit in the imaging process and thus improves the spatial resolution, and it might help to mitigate the influence of coherent effects in the transition radiation emission process which was observed already in the visible region. Proof-of-principle experiments showed the potential of EUV radiation based beam diagnostics [7,8], but in these experiments only a small portion of the TR spectral range was utilized because of the use of reflective optics based on periodic multilayer mirrors.

Therefore, instead of a standard homogeneous TR target it was proposed to use a multilayer radiator (multilayer X-ray mirror), which concentrates the emission in a quasi-monochromatic band in the EUV spectral region.

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 [3-6] have been carried out for MXM generation in the X-ray region with photon energies of E_γ=6-15keV. Recently, experimental investigations of the MXM mechanism in the EUV region started at the Tomsk Polytechnic University, using a 5.7 MeV electron beam [9,10].

This paper presents the results of a measurement of the angular distribution of EUV radiation from a multilayer radiator consisting of 50 Mo/Si bilayers placed onto a silicon substrate. The results are compared with the ones obtained from a monolayer radiator consisting of a silicon wafer coated with a layer of molybdenum.

EXPERIMENTAL SETUP

The experiment was carried out at the external electron beam of the microtron M-5 of Tomsk Polytechnic University with a total electron energy of E_e =5.7 MeV. The pulse repetition frequency amounted to 25 Hz, and the pulse duration of the extracted beam was 0.4 µs. The scheme of the accelerator complex together with the experimental setup are shown in Figs.1 and 2. The studies were carried out at the experimental chamber (16) of beam line II, cf. Fig. 1. The electron beam extracted from the microtron passed a bending magnet (3), a collimator system (4,6,7), and a second bending magnet (9).

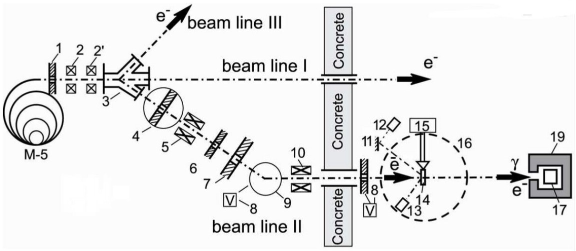

Figure 1: Scheme of the accelerator complex.

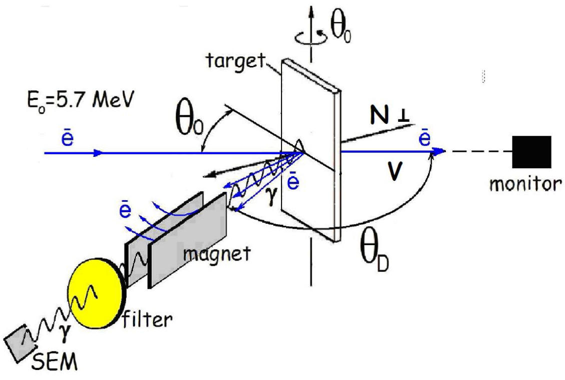

Figure 2: Layout of the experiment.

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The transverse beam shape at the target (14) in the center of the experimental chamber was close to a circle with a diameter of 2-3mm, and the beam charge amounted to 4 pC per pulse of beam ejection. Monitoring of the beam current of the accelerated electrons was carried out by a NaI(Tl) detector (17) located at a distance of 1200mm behind the target.

The radiation yield in the EUV range was measured by the secondary electron multiplier SEM-6 [11]. The detector was located in the median plane of the accelerator at a distance of 140 mm from the target onto a rotator that allowed to scan the angular distribution of the radiation emitted from the target in the range of $\theta_D = 20^o$ up to $\theta_D = 160^o$ with respect to the electron beam axis. Permanent magnets and diaphragms were mounted between target and detector along the direction of radiation propagation for cleaning the photon beam from electrons scattered at the target.

The spectral range of the registered radiation was defined by the detection efficiency of the SEM-6 [11] and the absorption filter. The entrance window of the SEM-6 had a diameter of ∅=10mm. The detector was surrounded by a lead shielding. As periodic target, a multilayer X-ray mirror consisting of 50 Mo/Si bilayers with a period of d =113.2 Å was used. The multilayer was deposited onto a silicon wafer with dimensions of 40x40x0.53 mm^3. The thicknesses of the alternating Si and Mo layers were a=79.2 Å and b=34 Å (a+b=d) respectively.

The second radiator (monolayer target) consisted of a silicon wafer with dimensions of 40x10x0.68 mm^3 and a 50 nm thick Mo layer at the entrance surface.

METHODS AND RESULTS

The main goal of the experiment was to demonstrate that the multilayer target generates an additional yield of EUV radiation because of the periodical structure. To observe and establish this phenomenon, the EUV yield from the periodical structure was compared the one from an ordinary homogeneous slab, the monolayer target.

According to [2-4], the expected MXM excess should be observed at the photon energy E_γ defined by:

$$E_\gamma = \hbar\omega = \frac{2\pi\hbar c}{d}\,\frac{\sin\theta_O}{\beta^{-1}-\sqrt{\varepsilon(\omega)}\,\cos\theta_D}, \quad (1)$$

with β=v/c the reduced electron velocity, d the multilayer structure period, $\varepsilon(\omega)=1-[a(1-\varepsilon(\omega)_{Si})+b(1-\varepsilon(\omega)_{Mo})]/d$ the dielectric constant averaged over a structure period, and $\varepsilon(\omega)_{Si}$ resp. $\varepsilon(\omega)_{Mo}$ the dielectric constants of pure silicon and molybdenum. θ_o is the Bragg angle and θ_D the angle of observation.

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 $E_\gamma=60$ eV should be generated according to equation (1).

Unfortunately, together with the MXM component, ordinary TR is emitted in the same direction. But the main yield of this TR is expected to be in the softer range of photon energies at E_γ <40 eV, therefore a thin (t=1μm) Al filter has been used to suppress this softer TR part.

In Figs. 3 and 4 measurements of angular distributions using the 1μm thick Al filter are shown. Figure 3 (curve 1) shows the angular distribution for the radiation from a silicon target with molybdenum coating. Curves 2 and 3 correspond to angular distributions measured with homogeneous Si targets. Curve 2 is measured for a target with polished surface, curve 3 for a target with rough surface (the reverse side of the multilayer mirror substrate). As can be seen from this figure, no distinctive features of TR can be observed, showing that the TR photons were absorbed by the Al filter. At the same time, the angular distribution of radiation from a multilayer target (curve 1 in Fig. 4) exhibits a double-lobe structure with a central minimum at $\theta_D=135^o$ and a characteristic angular peak distance of $\Delta\theta_D\approx10^o$. For a better

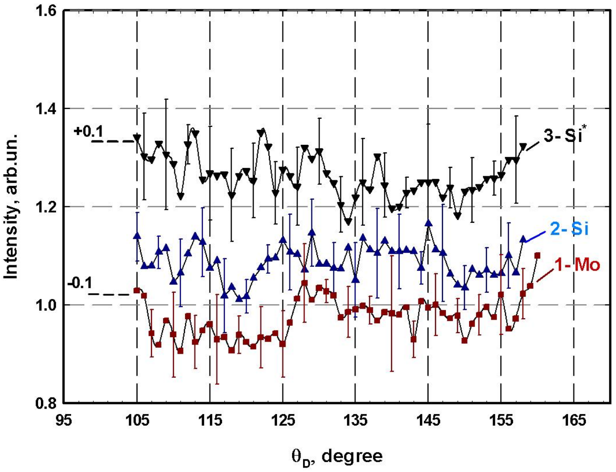

Figure 3: Angular distributions of radiation from uniform targets. (1) Mo target, (2) polished Si plate, (3) unpolished Si plate.

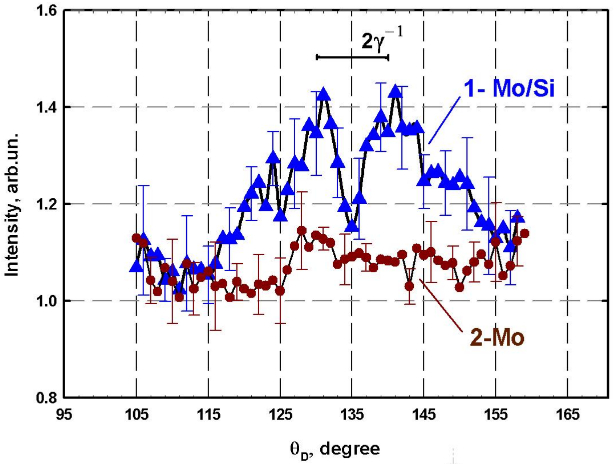

Figure 4: Angular distributions of radiation from (1) the multilayer Mo/Si mirror, (2) the uniform Mo target.

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comparison, curve 1 from Fig. 3 is plotted again and indicated as curve 2 in Fig. 4.

Thus, according to the results of the angular distribution measurements, an additional component of radiation is present in the radiation generated at a multilayer target. The origin of this component can be explained by the generation mechanisms of DTR and/or PXR in a periodic structure of a multilayer X-ray mirror. Taking into account the data concerning the detector efficiency from [11] , the calculated transmittance of the 1µm thick Al foil [12] and the transmittance of an additional Al_2O_3 oxide layer with thickness t=15nm [13], a rough estimate of $dN/d\Omega \approx 2.4x10^{-4}$ ph/sr/e^- for the angular density of MXM at the peak position can be estimated. This result is close to the value $dN/d\Omega \approx 4.6x10^{-4}$ ph/sr/e^- calculated according to the theory presented in Ref. [5].

CONCLUSION

The experimental investigation of the EUV TR angular distributions generated by 5.7 MeV electrons in multilayer structures and targets with homogeneous composition indicates that the periodic structure of the target results in an additional contribution to the radiation yield. The observed double-lobe angular distribution with central minimum at $\theta_D = 135^o$ and peaks distance of about 10^o can be explained by the mechanisms of DTR and/or PXR generation from the periodic structure of a multilayer X-ray mirror [2-5].

From the experimental data, it can be seen that there is a significant background contribution from characteristic radiation and bremsstrahlung from the target material. This background can be reduced to a large extent by reducing the thickness of the multilayer structure substrate down to several microns or even less.

The obtained results show that by using a multilayer target, in principle it should be possible to increase the intensity of the radiation in the EUV range. This is an important step towards the application of EUV TR for beam diagnostic purposes to image the transverse beam profile with a sufficient high signal-to-noise ratio. As next step it is planned to carry out an experiment at the 855 MeV microtron MAMI of the Institute of Nuclear Physics, J. Gutenberg University (Mainz, Germany). The scheme of this experiment is shown in Fig. 5. The electron beam interacts with a Mo/Si target which is optimized for 90° geometry and a monolayer Mo-coated silicon wafer target, generating both ordinary TR and TR from the MXM. The radiation passes a set of interchangeable filters, including an optical band pass filter and Al foils. The spatial distribution of the radiation is recorded with a scientific grade CCD camera (Andor DO434 BN [14]). This experiment will allow to compare intensities of the measured radiation, and to conclude about prospects to use EUV TR for beam size imaging diagnostics.

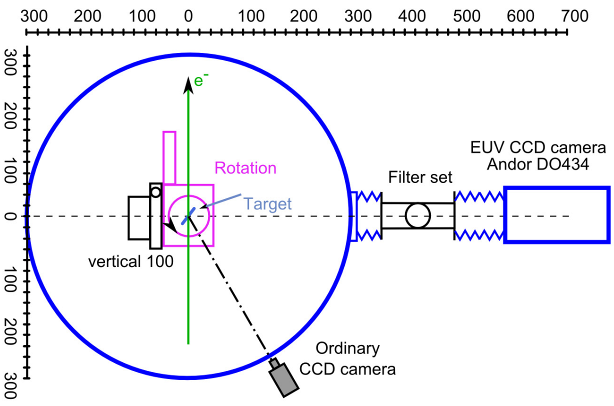

Figure 5: Scheme of the planned experiment.

APPENDIX

We would like to thank I.A. Artyukov for his help with the manufacturing of the Mo/Si targets.

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