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Research of the polarization bremsstrahlung of relativistic electrons in polycrystalline targets

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ABSTRACT

The collimated spectra of polarization bremsstrahlung (PB) produced by 7 MeV electrons in Al, Ni, Cu, Mo and W poly crystalline foils are measured and the angular dependences of the PB characteristics are studied. A comparison of the experimental results with theoretical predictions is performed. Polarization bremsstrahlung sensitivity to texture and grain size of the target in the backscattering geometry is shown. The possibility of developing a new method based on the characteristics measurement of the coherent PB component for the diagnostics of polycrystalline materials is considered.

1. Introduction

Polarization bremsstrahlung (PB) appears in the interaction process of a fast charged particle with an atom due to the scattering of the particle Coulomb field by the atomic electrons [1–3]. The effective impact parameter of the interaction between the incident particle and an atom is determined by the particle energy and can substantially exceed interatomic distance in a condensed medium. Because of this feature, PB formed in condensed medium becomes sensitive to the atomic structure of the medium. PB coherent peaks were observed for the first time during the interaction of 2.4 MeV electrons with a polycrystalline aluminum foil [4]. The sensitivity of PB to the texture distribution in polycrystals was demonstrated in [5,6] where the PB peaks were measured during the interaction of 150 MeV electrons with a molybdenum foil. These circumstances stimulate theoretical and experimental studies of the coherent PB component to develop a new method for structure diagnostics of polycrystalline materials.

The traditional approach for the diagnostics of polycrystalline samples (Debye–Scherrer method) is based on the angular measurements of quasi-monochromatic X-rays scattered by the sample [7]. Nowadays EDXD (energy dispersive X-ray diffraction) are widely applied for atomic structure diagnostics. EDXD methods are based on spectral measurements of scattered wide-band X-ray flux [8]. The primary probing flux of EDXD approach consists of free photons and the researched layer depth in the target is limited by the absorption of primary and diffracted fluxes. The use of virtual photons of the relativistic electron Coulomb field for EDXD has been proposed in [9]. PB spectrum is formed inside the target and the researched layer depth is larger than for traditional EDXD. It was shown [9–13] that PB spectra measurement allows to obtain information about the target structure. PB spectrum essentially depends on the observation angle (the angle between the propagation direction of the electron beam and the detector axis). The observation angle defines the position of PB coherent peaks in the spectrum. This important circumstance allows identifying the PB peaks in the measured spectrum, which usually contains background peaks with a fixed position.

The most suitable geometry to apply PB for target structure diagnostics is detecting the PB signal in the direction opposite to the velocity of emitting electrons (backscattering geometry – BS). It was shown [13,14] that the amplitude of PBBS peaks is proportional and their spectral width is inversely proportional to the square of the electrons energy. This feature allows to determine the structure of an elementary cell of the target with high accuracy. It should be noted that the research of the parametric X-ray radiation in the backscattering geometry from a perfect crystal [15] shows the narrowing of the detected peaks in the considered geometry.

This work presents a detailed comparison of collimated PB spectra measurements from Al, Ni, Cu, Mo and W foils with the

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theoretical models [9,13] for different observation angles. The effect of PBBS peaks narrowing is shown. The measurement of PBBS from a Cu textured foil shows the sensitivity of coherent peaks amplitude to the target orientation with respect to the electron beam. The results of PBBS research in a Ni polycrystal with submicron grain size show the possibility of PBBS applying for structure diagnostics of nano-dimensional structures. The PBBS spectra from Al, Ni, Cu, Mo and W poly crystalline foils are presented as well.

2. Experimental setup

The 7 MeV microtron of the P.N. Lebedev Physical Institute RAS was used as relativistic electron source for the development of the experimental setup. The setup has been upgraded several times and its modern scheme for PBBS research is presented in Fig. 1.

The electron beam 2 with 7 MeV energy and 40 mA current per pulse was generated by the microtron 1. The electron beam time structure was 50 Hz with a 4 μs pulse duration.

The first bending magnet 4 (the nearest microtron) directed the electron beam in the vacuum channel through two round aperture carbon collimators 3. The collimators have an internal diameter of 3 mm and the distance between them was 1.5 m.

The next bending magnet deflected the beam out of the X-ray background generated in the interaction process of the beam with the collimators 3.

The two pairs of quadrupole magnetic lenses 5 determined the angle divergence of the beam, the magnetic corrector 6 performed the beam deflection along the vertical axis. The third magnet directed the beam into the target chamber. The lenses, corrector and magnets allowed to control the beam divergence and position in the target location.

The orientation of the target 8 relative to the electron beam was controlled by the goniometer 9 with a 0.01° accuracy in the horizontal plane and with the possibility to move the target out of the beam. The position of the beam inside the channel and its current were controlled by a proportional gas chamber 10 and a Faraday cup 11. The X-ray signal from the target was formed by round aperture collimators 13 and measured by the detector 14. The microtron 1, collimators 3 and detector 14 were shielded by lead 15 for background suppression.

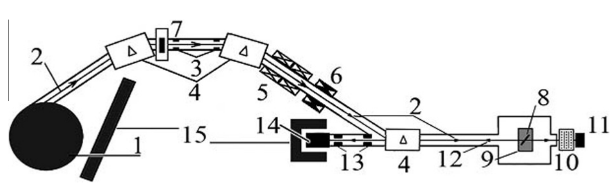

Fig. 1. Experimental setup.

The pressure inside the chamber of the target location was better than 10^{-5} torr. The vacuum volume of the microtron can be separated from the vacuum channel by the gate-valve 7.

The internal sizes of the collimators 13 were chosen in order for the detector 14 to observe the target 8 and the target holder only. The target holder was made of polymethyl methacrylate (PMMA) for background suppression.

3. PB spectra at angles of 75–90°

The collimated PB spectra from Al and Cu polycrystalline foils were measured in the forward hemisphere by an energy dispersive X-ray p.i.n. detector with a 200 eV resolution. The observation angles between the electron beam axis and the detector axis were 90°, 83° and 75° while the solid angle was $1.5 \cdot 10^{-6}$ sr. The orientation angle between the target surface and the electron beam axis was 45°.

Fig. 2a presents the spectrum of PB from the 8.5 μm thick aluminum foil measured in [10]. Hereinafter, the statistical errors are shown. Two peaks are clearly manifested in the spectrum, and the existence of the third peak is also visible. According to a Gaussian fit the positions of the peaks are 3782 ± 16 eV (111), 4560 ± 36 eV (200) and 6273 ± 19 eV (220). The spectrum contains an external background from the microtron, whose spectral shape is close to the exponential function. Measurements without the target show that this background contribution equals 24% of the main peak events. The exponentially distributed background has two sources. The first source is the bremsstrahlung of electrons in the target. The other part of the exponentially distributed background comes from secondary photons reemitted on the inner surface of the target chamber and the detector channel. Theoretical estimations predict the existence of the PB incoherent component but the calculations performed for the conditions of the present experiment show that this background can be neglected. The third spectral peak includes the contribution of photons from the iron K_{α} line of characteristic X-ray radiation (CXR) 6403 eV, which is formed by the scattered electrons on the inner surface of the target chamber and the photon channel.

The PB spectrum measured from the aluminum target at a 75° angle is presented in Fig. 2b [11]. The maximum of the coherent PB peak shifts from 3.78 keV to 4.44 keV. The spectrum also contains the exponential background and the CXR peak of iron at 6.4 keV.

The results of the measurements are interpreted using the PB model of relativistic electrons in a polycrystal [9]. According to this model, the polycrystal is considered as an ensemble of randomly oriented microcrystallites so that the coherent Bragg scattering of the Coulomb field of fast charged particles is realized in each micro-crystallite independently. The suppression of the incoherent component is an important feature of PB in a polycrystal. This

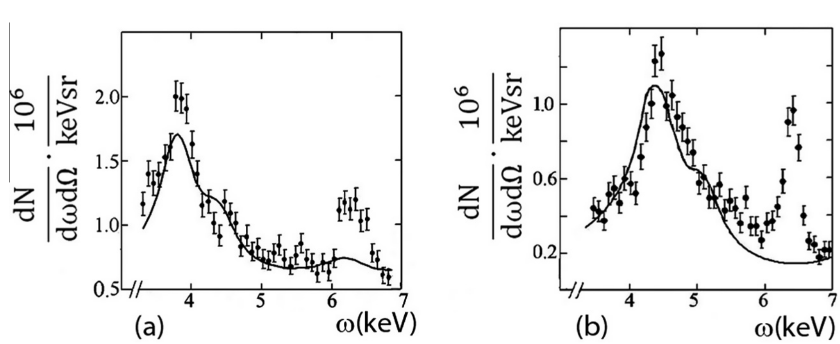

Fig. 2. PB spectrum measured from the aluminum target at the angles of 90° (a) and 75° (b).