



Research Paper

PARAMETRIC X-RAY RADIATION AND TEXTURE OF POLYCRYSTALLINE FOILS

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Abstract

The texture of polycrystalline foils of tungsten and nickel was studied using Parametric X-ray Radiation (PXR) generated by 7 MeV electrons. The PXR rocking curves from crystallographic planes (200) for tungsten and (220) for nickel were obtained. A comparison with similar measurements obtained using diffraction of broadband X-rays is presented. The comparison showed a good compliance of the results concerning the form of the rocking curves and the position of the maximums. However, a systematic discrepancy in the value of the Full Width Half Maximum was observed.

Key words: parametric X-ray radiation, polycrystalline foils, rocking curves, texture, polarization bremsstrahlung.

1. Introduction

The incidence of relativistic charged particles on crystalline structures provokes a dynamical polarization of the medium. Collective effects cause the medium to emit photons in the X-ray region. The radiation is generated during the coherent scattering of the charged particle Coulomb field by the crystalline structure. The characteristics of the produced radiation strongly depend on the parameters of the medium. For these reasons, this process is called Parametric X-ray Radiation (PXR) [1, 2].

Several works were devoted to the study of the possibilities to determine the parameters of matter

[1, 3–6] and of charged particle beams [7, 8] based on the PXR characteristics. PXR is also regarded as a promising source of tunable quasimonochromatic X-rays [9] which can be applied for instance in medicine [10]. In order to develop these applications, nowadays, the studies are performed to determine the conditions for which PXR will achieve maximum intensity [11–13].

Recently, it was shown that PXR from textured polycrystalline foils can be described using the theory of mosaic crystals, regarding the texture pattern of the target as the mosaic parameter [13]. The results show the possibility to determine the texture of polycrystalline foils using PXR.

In this work, the dependence of the PXR yield on the orientation angle (PXR rocking curve) is determined. The rocking curve can be used to study the dislocation density, mosaic spread, curvature, misorientation, and inhomogeneity.

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2. Experimental setup

The experimental setup presented in Fig. 1 was developed in the Department of High Energy Physics of the P.N. Lebedev Physical Institute of the RAS. The 7 MeV microtron was used as a source of relativistic electrons. The characteristics of the beam of electrons measured at the target position were as follows: 20 nA mean current, ≤ 2 mm spot size, $\leq 0.15^\circ$ divergence. The position and intensity of the beam of electrons were controlled by a proportional gas chamber (PC) and a Faraday cup. A detailed description of the experimental setup was given in [14].

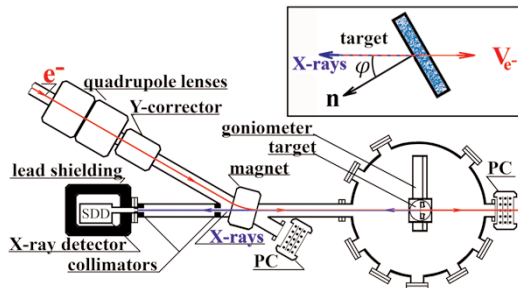


Fig. 1. Experimental setup: n stands for the normal vector of the target surface

Two textured polycrystalline foils were used in the experiment: a 20 μm thick tungsten and a 40 μm thick nickel. The PXR rocking curves were obtained changing the orientation angle φ , which was controlled by a motorized goniometer with a 0.01° rotation accuracy.

The solid angle $\Omega = 1.5 \times 10^{-7}$ sr of registration was determined by tungsten collimators installed before the detector. Under the mentioned conditions, the detector registered the radiation from the target and the target holder only, which was made of PMMA (methyl methacrylate) for background suppression. An Amptek X-123 FAST SDD silicon drift detector with a 145 eV energy resolution at 5.9 keV was used. The signal was registered in the backward geometry, as shown in Fig. 1.

Before PXR could be applied in structure diagnostics, it is important to compare the measurement results with existing technics of diagnostics such as the X-ray structure analysis. For this reason, the dependence of the diffracted broadband X-rays yield on the orientation angle (XRD rocking curves) was measured. Broadband X-rays were generated by an X-ray tube provided with a tungsten anode and a 48 μ focal spot size. The angle $2\theta_B$ was 136° for the tungsten foil and 88.5° for the nickel foil, where θ_B is the Bragg angle. In both cases the voltage was set to $U = 20$ kV and the emission current to $I = 300$ μA . The detector solid angle was 3.7×10^{-6} sr; for these conditions, the system angular resolution was 1° . In order to perform the measurements in the closest possible conditions, the target holder and the goniometer

were not changed in both experiments. Additionally, it is important to mention that the target was not removed from the target holder during the whole process to avoid accidental changes in the target position.

Both experiments were performed in vacuum systems which pressure was $\sim 10^{-6}$ Torr.

3. Results and discussion

Two PXR spectra from tungsten polycrystalline foil obtained under different values of the orientation angle φ are shown in Fig. 2. From left to right the peaks correspond to the PXR peaks obtained from (200) plane, a weak manifestation of the PXR peak obtained from the (310) plane, the L_I line of Characteristic X-ray Radiation (CXR). Spectra are shown in the region up to 8 keV, because the intensity of the CXR L_α line is more than two orders stronger than the PXR peak intensity. It should be mentioned that the spectra are presented without background subtraction, smoothing of the curves or any mathematical procedure.

It is easy to observe that the PXR peak intensity changes by more than four orders when the orientation angle φ changes. This effect is confirmed by the unchanged intensity of the CXR L_I peak in spectra of Fig. 2. Such behavior is typical for textured polycrystals [15]. If no texture is present in the target, the peaks have a continuous intensity when the orientation angle changes [12]. This result confirms the behavior observed in the PXR spectrum generated from a copper textured polycrystalline foil (Fig. 5 from [16]). Similar results were obtained for the nickel target (Figs. 2 and 3 from [17]).

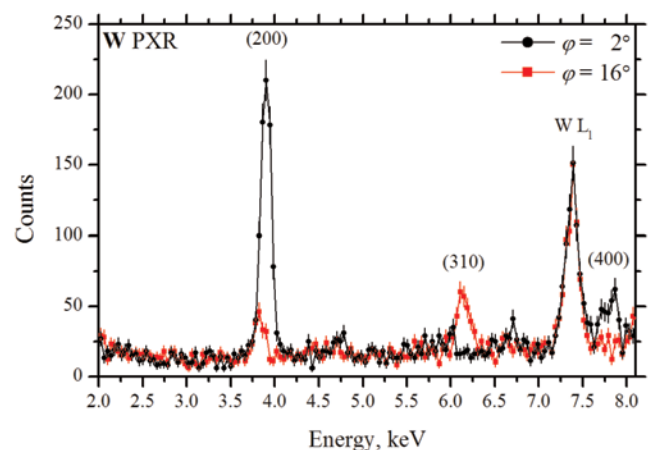


Fig. 2. PXR spectra from the tungsten polycrystalline foil for two random orientation angles

The crystalline structure of the sample determines the orientation of the crystallographic planes produced by the rolling process. For example, such elements as tungsten packaged in a body centered cubic (bcc) cell acquire a predominant orientation of the

(100) plane parallel to the surface of the sample, meanwhile such elements as nickel packaged in a face centered cubic (fcc) cell acquire a predominant orientation of the plane (110) parallel to the surface of the sample [18].

For the above reasons, the rocking curves from the (200) plane of tungsten and from the (220) plane of nickel were measured. It should be remembered that it is not possible to measure the diffraction from the (100) and (110) planes since it is suppressed due to the form factor of the crystalline structure.

The PXR rocking curves from planes (200) and (220) were calculated using a monitoring signal to avoid the influence of external factors such as the beam of electrons intensity and geometry. In the backward geometry, the CXR yield can be used as an additional signal since only in this configuration, the influence of the geometry factor on the ratio CXR yield/number of electrons that interacted with the target is absent. The normalization was performed using the integral number of photons from the CXR lines L_α and M_α in case of tungsten and from the K_α line in case of nickel. In every case, the background was subtracted. Fig. 3 shows the PXR and XRD rocking curves. It should be noted that the contribution of diffracted free X-rays to the PXR yield is negligible [19].

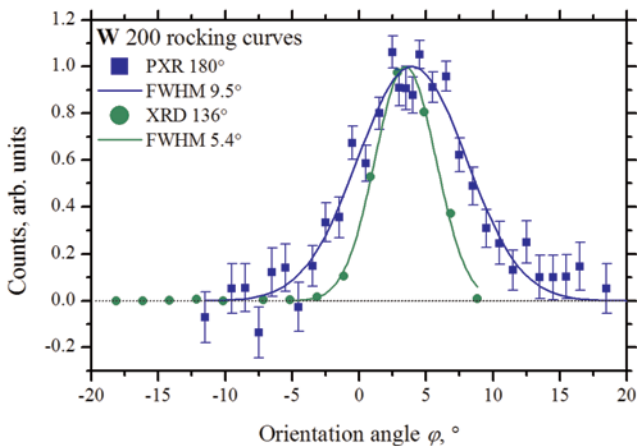


Fig. 3. PXR and XRD rocking curves from the (200) crystallographic plane of tungsten. The lines represent the fitting by the Gaussian function

Fig. 3 shows strong peaks which maximums correspond to the most probable orientation of the (200) plane. The maximum position and the FWHM of the PXR rocking curve are $4.0^\circ \pm 0.2^\circ$ and $9.5^\circ \pm 0.4^\circ$; similar measurements for the XRD rocking curve showed the following values $3.46^\circ \pm 0.08^\circ$ and $5.4^\circ \pm 0.1^\circ$. A good agreement of the maximum positions of the curves and their form can be observed; however, special attention should be paid to the

FWHM value, which is significantly smaller for the X-ray diffraction measurement.

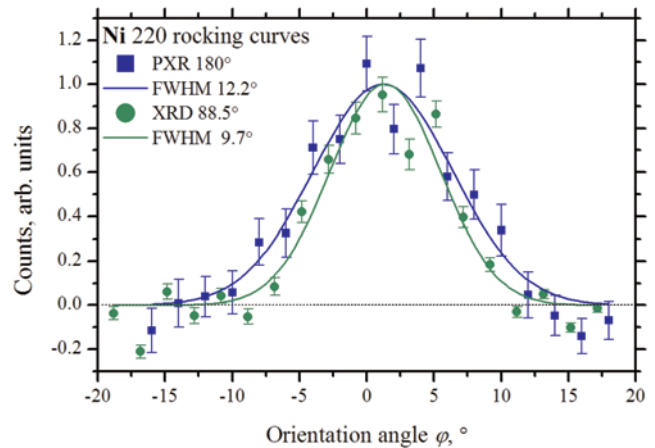


Fig. 4. PXR and XRD rocking curves from the (220) crystallographic plane of nickel. The lines represent the fitting by the Gaussian function

Fig. 4 presents the PXR and XRD rocking curves obtained from the nickel (220) plane. The position and the FWHM of the rocking curves are as follows: $1.2^\circ \pm 0.4^\circ$ and $12.2^\circ \pm 0.9^\circ$; $1.4^\circ \pm 0.5^\circ$ and $9.7^\circ \pm 0.9^\circ$, respectively. It is important to highlight that the obtained results are similar to those presented in Fig. 3, which is a good correlation of maximum positions and form of the curves. The FWHM is significantly smaller for the XRD rocking curve.

The difference in the FWHM values measured using PXR analysis and XRD analysis is 4.7° for tungsten and 4.6° for nickel. Since the difference is close, and the targets are completely different, one can assume that the discrepancy reason is linked to the method used to perform the measurements.

The Coulomb field of the incident electron (beam of pseudo-photons) has an initial angular distribution, which is proportional to γ^1 , where γ is the Lorentz factor [20]. This angular distribution can be compared with the initial angular divergence of a photon beam in X-ray crystallography methods. Since this value $\gamma^1 \approx 3.8^\circ$ is comparable with the difference obtained in the FWHM. It is possible to suppose that the γ^1 influences the overall result. In order to reduce this influence, it is necessary to increase the energy of the incident particles.

4. Conclusions

The results limit the possibility to apply PXR produced by 7 MeV electrons to determine the rocking curves of textured polycrystalline foils. The initial distribution of the charged particle Coulomb field introduces a constant to the FWHM rocking curve value which can be comparable with its intrinsic value.

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