НИУ БелГУ
BELGOROD STATE UNIVERSITY (BSU)
International Scientific and Educational Laboratory of Radiation Physics

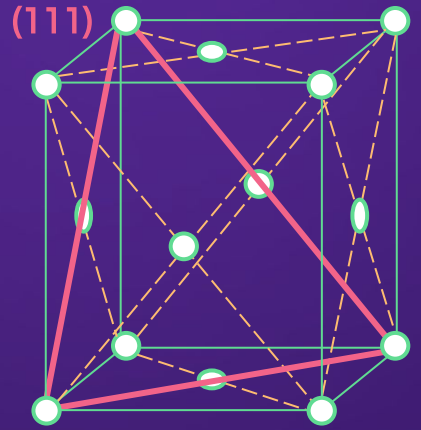
Parametric X-ray radiation of relativistic electrons in powder targets

Dubna, 2023

What is parametric X-ray radiation?

Parametric X-ray radiation is generated as a result of the interaction of charged particles with periodic structures. The Coulomb field of incident charged particles polarizes the electron shells of the atoms of the medium, they emit, and the coherent component of this radiation is parametric X-ray radiation [1]. The radiation characteristics depend on the falling charged particles, the observation angle, the characteristics of the target. For this reason, the radiation generated in crystals differs from the radiation observed in polycrystals or powders.

The unique property of PXR, compared to other radiation mechanisms, is the generation of photons at large angles relative to the incident relativistic particle direction. When a relativistic electron enters a target its electromagnetic field can be represented as a superposition of virtual photons. This electromagnetic interaction is equivalent to the interaction of a photon beam within a crystal, so we can use the results from the theory of x-ray diffraction.



[1] Potylitsyn A. P., Ryazanov M. I., Strikhanov M. N. et al. Diffraction Radiation from Relativistic Particles / Potylitsyn A. P., Ryazanov M. I., Strikhanov M. N. et al. // Springer, Berlin Heidelberg. — 2010. — No 239. — p. 219.

A little bit about the history of the PXR study

The first theoretical calculations about PXR appeared in 1957 [1]. It was first experimentally detected in Tomsk at the Sirius synchrotron during the interaction of an electron beam with an energy of 900 MeV with a diamond target with a thickness of 350 microns in 1985 [2].

After the first case of registration of PXR, similar studies began to be conducted both in Russia and in other countries: in the USA, Japan, Germany, France, Armenia and Ukraine.

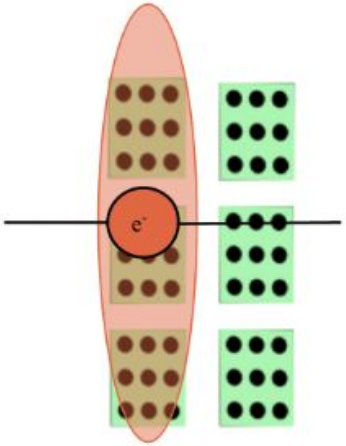
Parametric X-ray radiation in crystals has been studied for more than 40 years, PXR in polycrystals has been studied for the last 20 years. The main difference is that in a crystal, radiation is generated from only one plane, while in polycrystalline targets, radiation is generated from all planes. However, the results obtained during the generation of PXR from polycrystals showed a strong dependence of peaks with energies on the structural parameters of the polycrystal and the viewing angle. In this regard, our Belgorod group decided for the first time to investigate the mechanism of PXR generation in powder targets, that is, in disordered media. The advantage of powder targets lies in the absence of preferential orientation of crystallites, i.e. in the absence of structure.

[1] Feinberg, Ya. B. Parametric X-ray emission of fast charged particles in periodic media / Ya. B. Feinberg, N. A. Khizhnyak // JETF. -1957. – Vol.32, No4. – pp. 883-885.

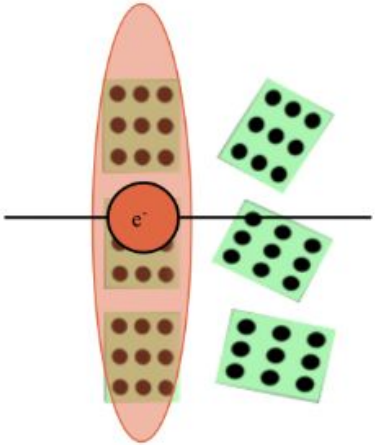
[2] Adishchev, Yu. N. Experimental detection of parametric X-ray radiation / Yu. N. Radishchev, V. G. Baryshevsky, S. A. Vorobyev et al. // Letters of the ZhETF. - 1985. – Vol.41. – p.295.

Mechanism of PXR

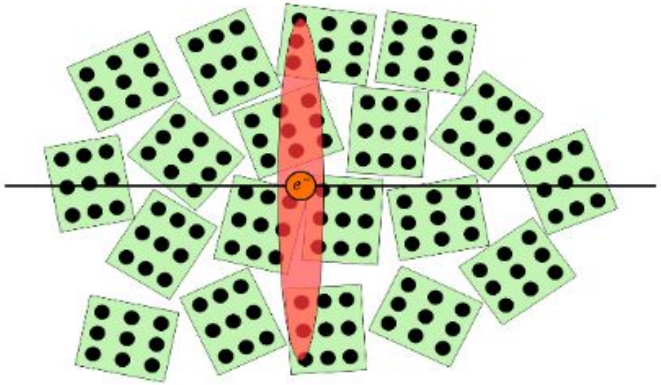
Crystal



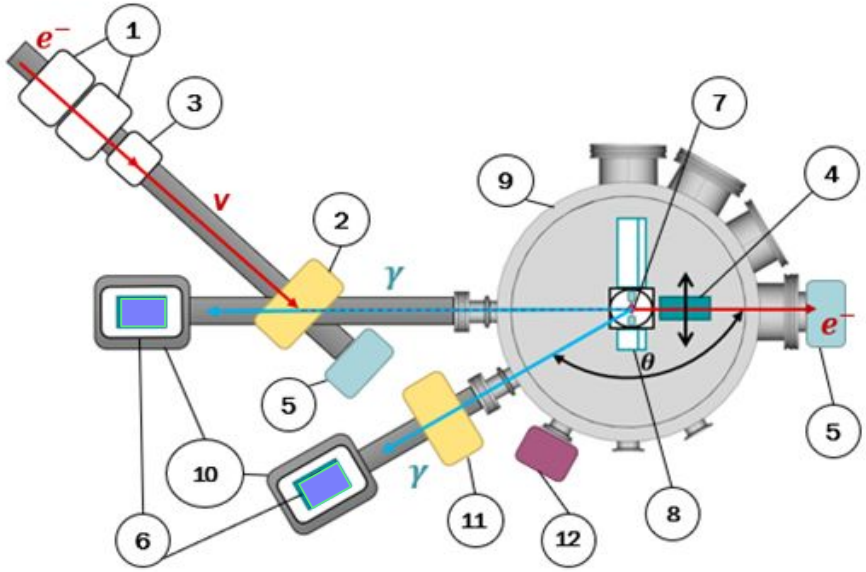
Polycrystal



Powder



Experimental setup



1 - a pair of quadrupole lenses
2 - rotary magnet
3 - magnetic corrector
4 - Faraday cup
5 - proportional camera
6 - semiconductor detectors
7 - target
8 - goniometer
9 - target vacuum chamber
10 - lead protection
11 - magnetic charged particle filter
12 - webcam

A microtron with an energy of 7 MeV was used as a source of relativistic electrons. The vacuum is approximately 10^{-7} Torr. The required vacuum is maintained by a three-stage pumping system, which consists of a pre-vacuum pump, a magnetic discharge pump and a turbomolecular pump.

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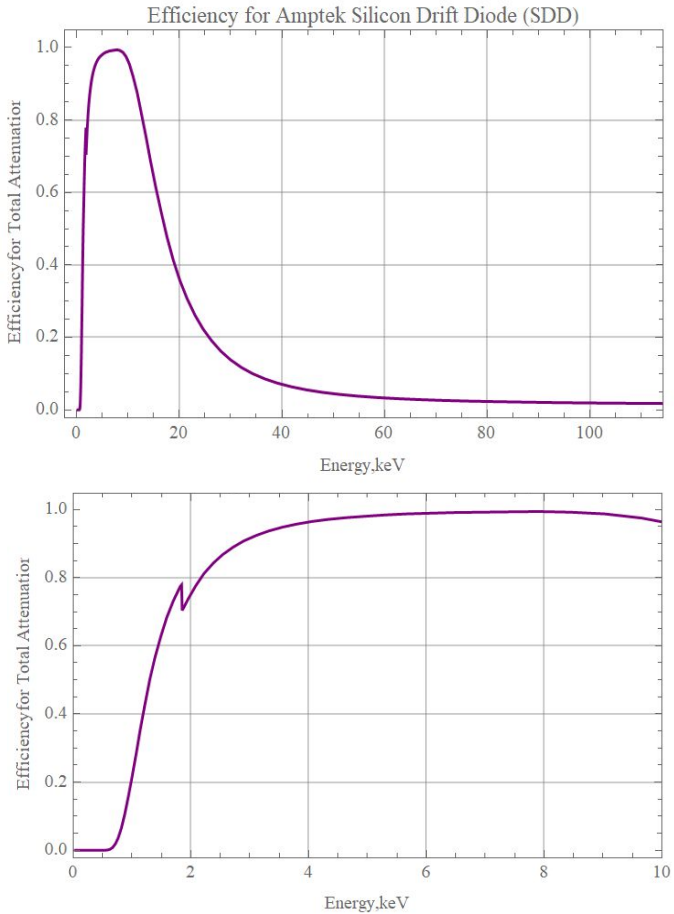
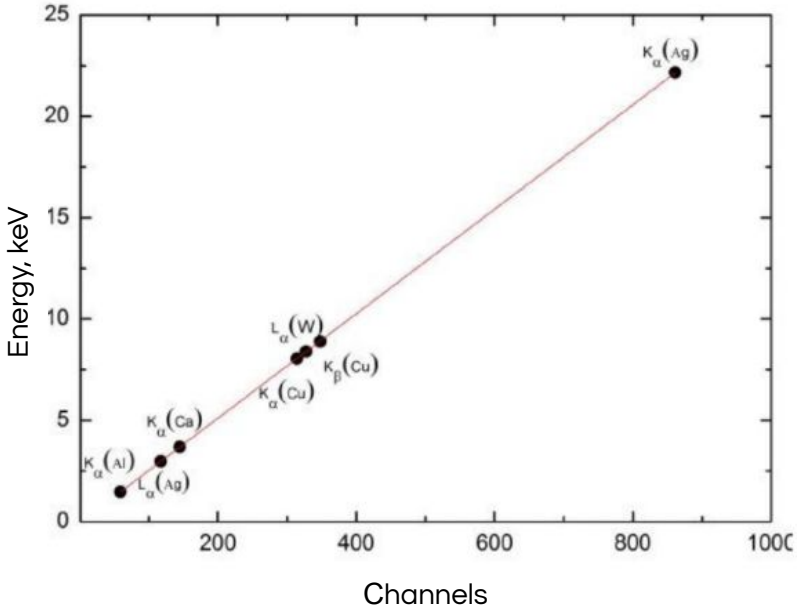
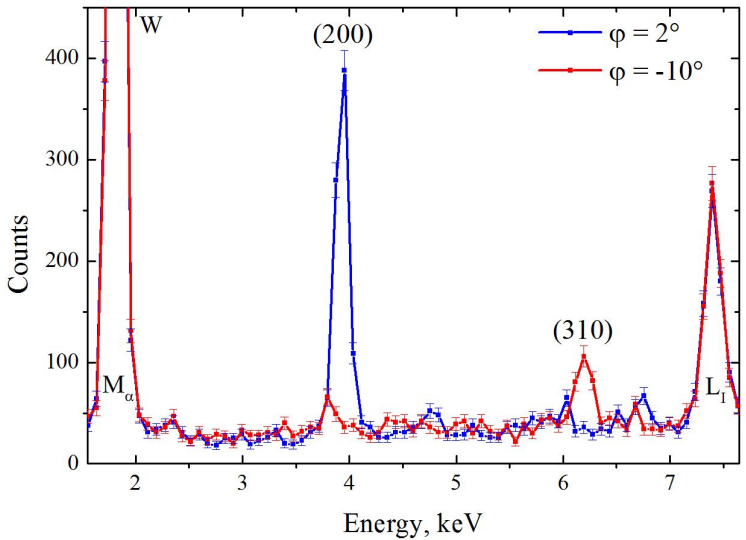
Detectors used



The energy resolution of the Amptek X-123SDD spectrometer used in the PXR generation experiments.



PXR studies in polycrystals



PXR spectrum of textured tungsten (20 microns foil)

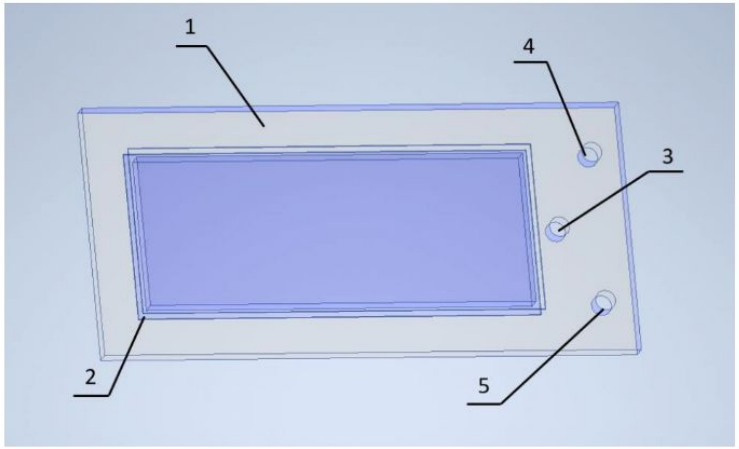
When changing the orientation of the target, the reflex from the plane (200) disappears and a reflex from the plane (310) appears.

This is due to the presence of texture in polycrystals. Therefore, the Belgorod group decided for the first time to conduct experiments with powders.

The advantage of powder targets lies in the absence of preferential orientation of crystallites, i.e. in the absence of structure.

Alekseev, V. I. Parametric X-ray radiation in polycrystals / V. I. Alekseev, A. N. Eliseyev, E. Irribarra, et al. // Problems of Atomic Science and Technology. – 2019. – V. 122. – P. 187–190.

The target for the experiment

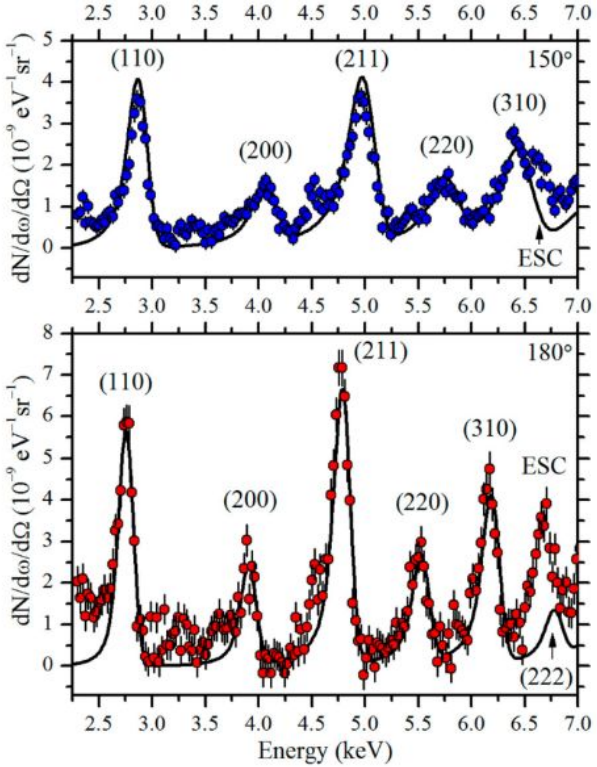


The target is a rectangular frame made of plexiglass with a thickness of 1 mm with a rectangular hole measuring 9 × 23 mm, which on one side was sealed with mylar film. The test powder was poured into the formed cavity to the edge of the frame and closed with an identical mylar film from the opposite side. In order to avoid destruction of the target under vacuum loading conditions, the internal volume of the target was not sealed tightly so that excessive pressure was not created inside it.

The picture shows the target used for the experiment: 1 – organic glass frame, 2 – mylar film, 3 – centering hole, 4 and 5 – mounting holes.

PXR studies in powders

In the first work on the study of PXR from powders, tungsten powder with a grain size from 0.8 to 1.7 microns was used as a target. The experimental results showed a good agreement with the kinematic theory of PXR.

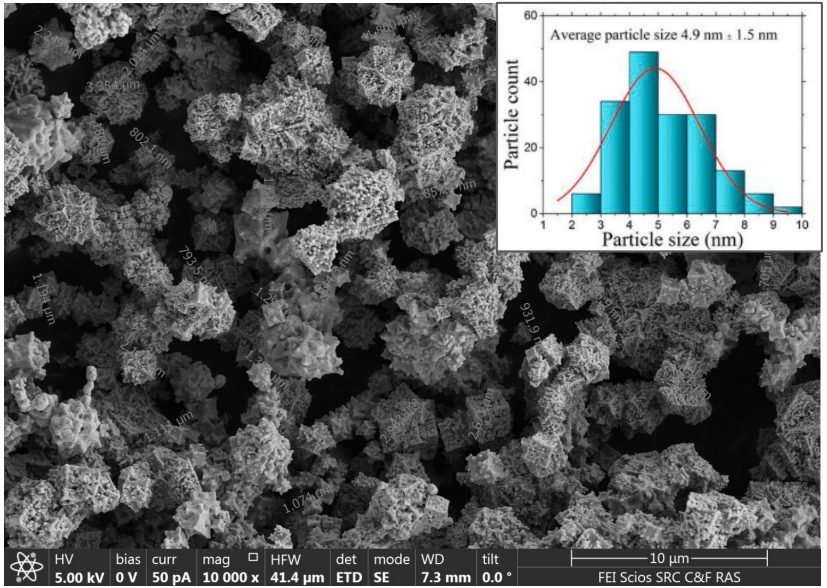


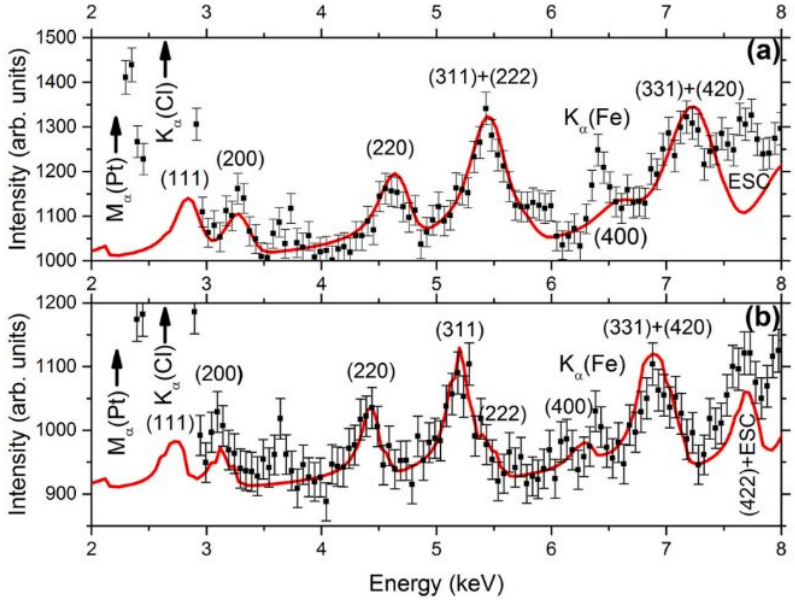
Plane	Calculated values for an observation angle of 150 deg, keV	Calculated values for an observation angle of 180 deg, keV
(110)	2.872	2.774
(200)	4.062	3.924
(211)	4.975	4.805
(220)	5.744	5.549
(310)	6.423	6.204
(222)	7.036	6.796

Alekseev, V. I. Parametric X-ray radiation from powders / V. I. Alekseev, A. N. Eliseyev, E. Irribarra, et al. // Physics Letters A. – 2019. – V. 383. – P. 770–773.

PXR studies in powders (Pt)

In the next experiments, powders with grain sizes less than 100 nm were selected as targets. The PXR spectra were observed at angles of 150 and 180 degrees relative to the electron velocity. During the experiment, PXR reflexes were observed in the energy range from 2 to 8 keV. Platinum powder with an average grain size of 4.9±1.5 nm was chosen as a target.





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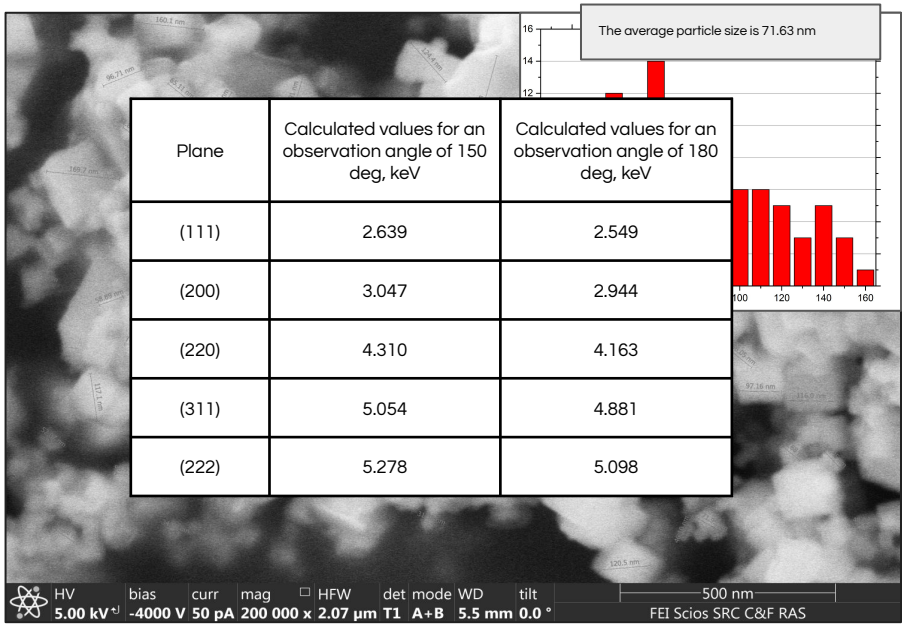
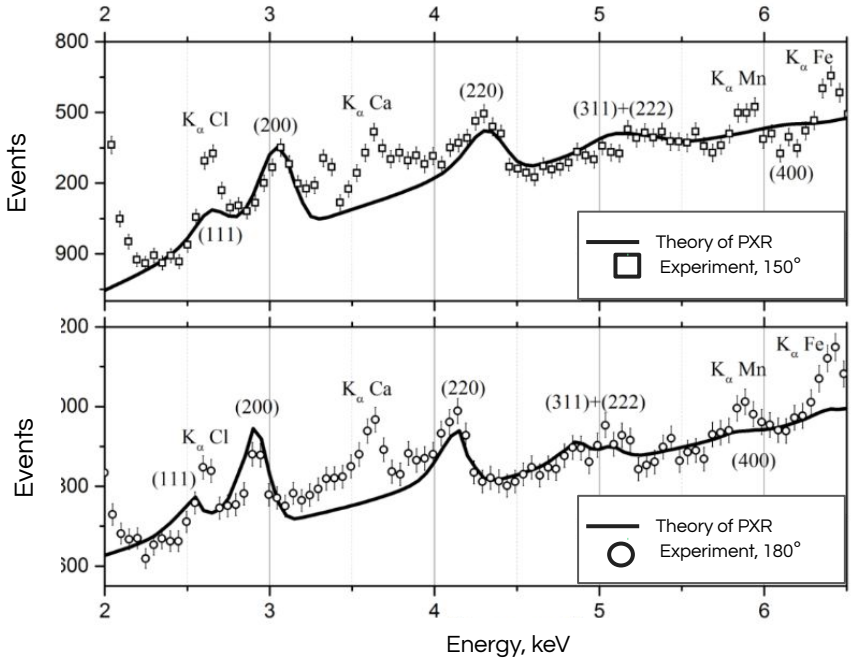
Alekseev V. I. PXR from nanopowders / Alekseev V. I., Eliseyev A. N., Irribarra E., et al. // Radiation Physics and Chemistry / 2022. – V. 202.

PXR studies in powders (MgO)

The PXR spectra were observed at angles of 150 and 180 degrees relative to the electron velocity. Similar experiments were carried out to register PXR from powders, however, non-metallic magnesium oxide powders with an average grain size of 71.63 nm were chosen as target.



Plane	Calculated values for an observation angle of 150 deg, keV	Calculated values for an observation angle of 180 deg, keV
(111)	2.639	2.549
(200)	3.047	2.944
(220)	4.310	4.163
(311)	5.054	4.881
(222)	5.278	5.098

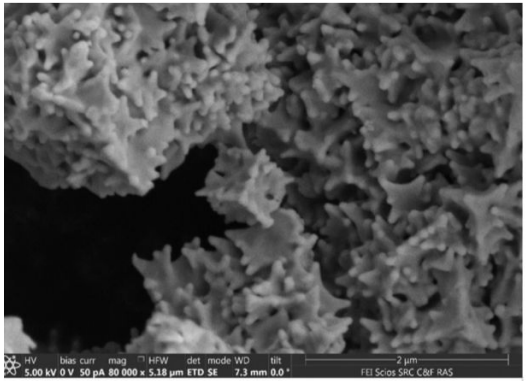


Dubna, 2023

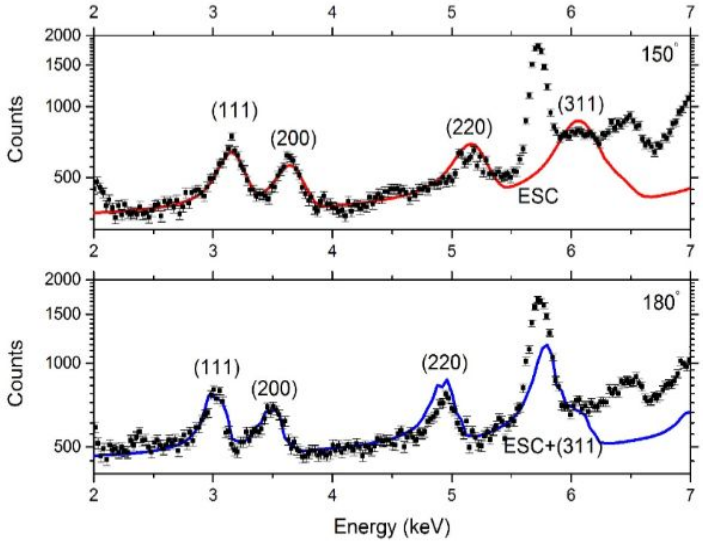
Kishin, I. A. Generation of parametric X–ray radiation from ultrafine powder of burnt magnesia / I. A. Kishin, E. Y. Kidanova, A. S. Kubankin et al. // Bulletin of the Lebedev Physics Institute – 2022. - No12. – p. 3.

PXR in nickel (Ni) powder

According to the calculated values for the nickel target, in the range from 3 to 7 keV, at observation angles of 150° and 180°, peaks from the planes should be visible (111), (200), (220), (311), (222), (400).



PXR spectrum of nickel powder



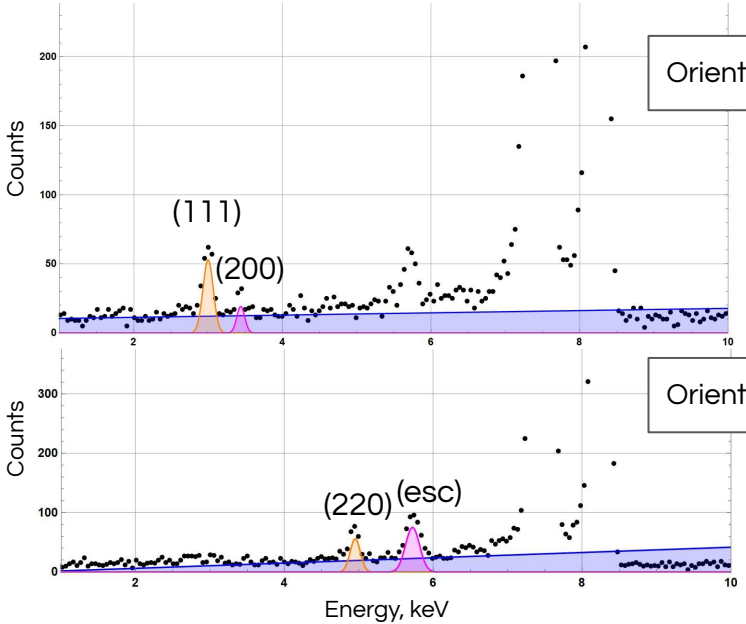
Calculated energy values of nickel PXR peaks for observation angles of 150° and 180°

Plane	Calculated values for 150 deg, keV	Calculated values for 180 deg, keV
(111)	3,155	3,047
(200)	3,643	3,518
(220)	5,151	4,976
(311)	6,041	5,835

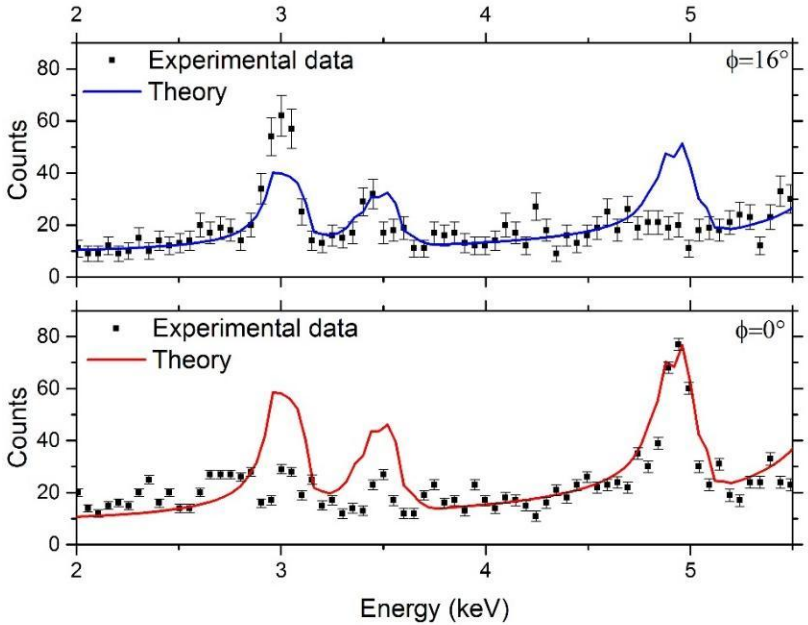
PXR nickel in a foil

When generating a PXR from a powder target, there is a good agreement between theory and experiment for all peaks of the PXR for two observation angles. The theory and experiment for nickel foil agree only in the position of the peak, and it is impossible to see the full set of peaks with one orientation of the target. This work is a continuation of the studies of PXR formed in powder targets. For the first time, a comparison of the PXR spectra formed in powder and textured nickel targets is presented in detail.

PXR spectrum of nickel foil



PXR spectrum of nickel foil with theory

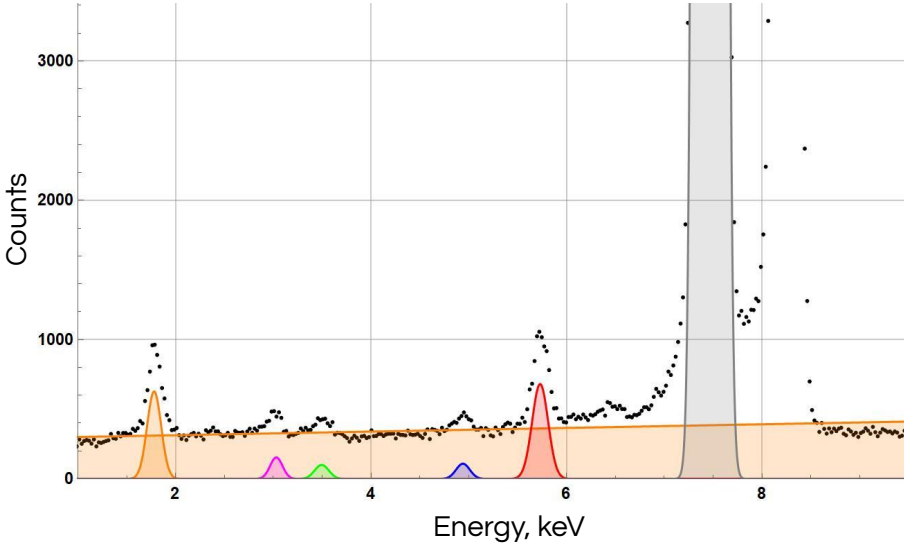


Comparison of FWHM peaks of PXR nickel in a powder target and in a polycrystal

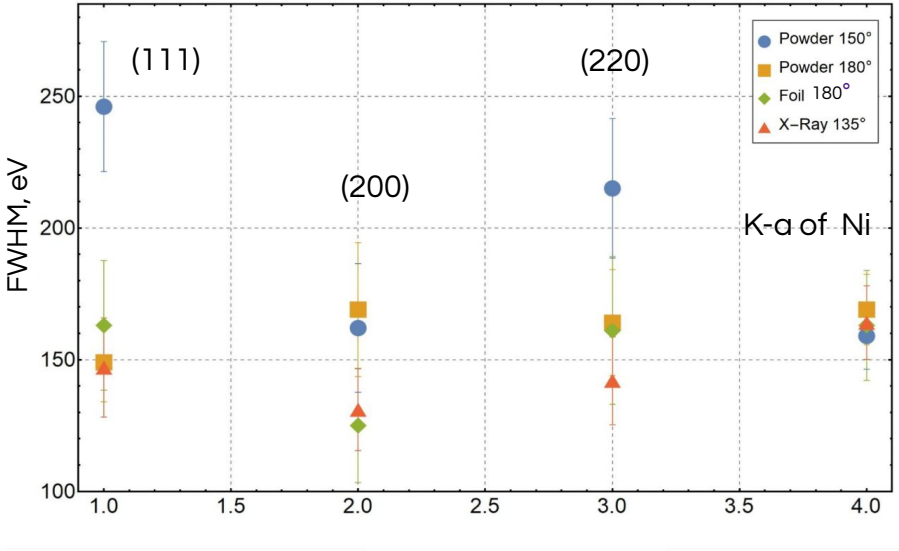
This work is a continuation of the studies of PXR formed in powder targets. For the first time, a comparison of the PXR spectra formed in powder and textured nickel targets is presented in detail.

The PXR spectra from powder targets agree well with the theory in shape position and relative intensity, while the PXR spectra from foil agree with the theory only in the position of the peaks. It is shown that the width of the spectral peaks is affected by the angle of observation and does not depend on the structure of the target.

Calculation of FWHM for nickel powder, 180 degrees



Calculation of FWHM for different samples



Results

- Experimental studies of parametric X-ray radiation produced by the interaction of relativistic electrons with powder targets and textured foils are shown.
- The difference in the obtained X-ray spectra is shown.
- Experimental data are compared with the kinematic theory of PXR
- The PXR from powder targets coincides with the theory in shape, position and relative intensity, while the PXR spectra from foils coincide with the theory only in the position of the peaks.
- The width of the spectral peaks depends on the observation angle
- The texture of the target has little effect on the width of the spectral peaks

Thanks!