LINEAR POLARIZATION OF PHOTONS PRODUCED BY THE ELECTRONS MOVING ALONG THE CRYSTALLOGRAPHIC PLANE IN A SILICON CRYSTAL

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We present the results of the polarization and intensity measurements versus photon energy E_γ=5-35 MeV for the photon beam produced by the electrons with the energies 1.2 and 1.5 GeV moving in the silicon crystal 500 and 290 μm thick along the (110) plane. The comparison with results of another research group and theoretical calculation indicates the qualitative agreement. The correlation in the shape of the radiation intensity spectrum and its polarization energy dependence is observed.

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INTRODUCTION

There are relatively small numbers of methods of polarized photon production in the energy range of 1-100 MeV. Not far ago the high polarisation degree was found for photon beam produced by high-energy electrons moving along crystallographic plane in crystal [1]. High intensity and polarization degree make such photon beam very suitable for the study of atomic nuclear structure as well as dynamic characteristics of nuclear reactions induced by polarized photons.

The intensity of such beams was actively investigated by the theoreticians and experimentalists during the last years. But, the studying of photon polarization has been started recently. Only some first experiments were devoted to the measurements of photon beam polarization [2,3]. The high polarization degree P_γ=0.6-0.9 near the characteristic maximum was observed in these investigations.

The theoretical investigation of the photon polarization is also at the very beginning now. The authors of work [2] give two possible methods of such calculations. But, as they mentioned, their results should be considered only as an illustration of some general approach.

Recently, rather interesting results were achieved in the theoretical calculation of the photon polarization on the base of "thermal-layer" model [3] that gave very good agreement with experimental data on diamond target. At the same time, similar analysis [4] performed for the silicon crystal does not give correct description of experimental polarization spectrum of [2].

The objective of our work was the experimental investigation of the soft part of linear polarization energy spectrum of photons emitted by high-energy electrons in the silicon crystal. It is very important to increase the quantity of experimental information in the energy region where it was observed disagreement with theory [4].

Moreover, it was supposed to carry out simultaneously the measurements of photon intensity spectrum. Such measurements were not performed in previous investigations. At the same time, the information about the intensity spectrum is very important to test the theoretical models. The experimental conditions of measurements have some parameters, such as initial electron beam monochromaticity, divergence, photon beam collimation etc., should be taken into account in the computation. Since the theoretical methods for intensity spectrum calculation were developed quite well even for thick crystals, these spectra may be used as test of correctness of experimental parameters accounting.

Some preliminary results were already represented in a previous paper [5].

EXPERIMENTAL TECHNIQUE

The experiments have been performed using the electron beam of 2 GeV LINAC of the National Scientific Center Kharkov Institute of Physics and Technology (NSC KhIPT). The experimental setup is shown in Fig. 1.

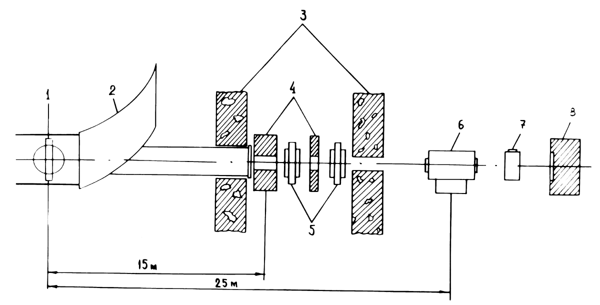

***Fig. 1**. Experimental setup: 1 - the goniometer with the target of a silicon single crystal, 2 - the deflecting magnet, 3 - the concrete shelding, 4 - the photon beam collimator, 5 - the cleaning magnet, 6 - the deuterium polarimeter, 7 - the ionization chamber, 8 - the quantometer*

The photon beam was generated by electrons moving in (110) plane of Si crystal. The electron energy (E_e) was 1200 MeV and 1500 MeV for 500 μm and 290 μm crystal thick correspondingly. The electron beam parameters at the crystal target location were:

monochromaticity ~1 %, divergence $\sim 10^{-4}$ rad. The photon beam angular collimation was $\Theta \sim 10^{-4}$ rad.

The polarimeter operation [6] is based on the measurement of the proton yield asymmetry (A) of the deuterium photodisintegration:

$A = P\Sigma$,

where P is the photon polarization degree and Σ is the asymmetry of the reaction γ+d=n+p.

The photon spectra, corresponding to the amorphous target, were measured with the same crystal.

EXPERIMENTAL RESULTS

As the result of the measurements, the proton energy spectra for three different crystal orientations corresponding to the direction of the photon polarization vector: the parallel ($N_{\|}$) and perpendicular ($N_{\perp}$) to the reaction plane as well as for the disoriented crystal (N_o) were obtained. The registered protons were considered as a result of direct photodisintegration of the deuteron. Thus, we were able to restore the photon energy spectra according the reaction kinematics. The possible contribution of protons generated at E_γ above the meson production threshold is small mainly due to the slope character of the photon intensity spectra ($\sim 1/E_\gamma$) and it does not exceed a few percents.

The photon beam polarization had been restored according to the formula:

$P_\gamma = A/\Sigma = (N_{\|} - N_{\perp})/(\Sigma\,(N_{\|} + N_{\perp}))$.

For the photon energy region above 10 MeV the deuteron photodisintegration asymmetry (Σ) values were taken from the experimental paper [7]. For lower energies E_γ, we used the results of the reaction asymmetry calculations based on the covariant gauge-invariant model with a Paris potential [8]. In this work, the interaction in the final state was considered in the form of re-scattering in the $^1S_0$ state, and it was obtained that deuteron photodisintegration asymmetry within the range E_γ=4-10 MeV is constant and equal to 0.99.

Our results are shown at Fig. 2 together with experimental data [2] obtained under the conditions very close to our measurements (silicon crystal 400 µm thick, (110) plane, and electron beam with the energy 900 MeV).

The upper part of Fig. 2 shows the radiation intensity extracted from our experimental data on the oriented crystal and normalized by the disoriented crystal case as following:

$\beta = (N_{\|} + N_{\perp})/2N_o$.

The beam polarization is represented at the down part of Fig. 2. In spite of the fact that polarization measurements of [2] were carried out with another experimental technique (Compton polarimeter), they are in qualitative agreement with ours measurements at initial electron energy E_e=1200MeV. However one can see that our experiment gave bigger polarization degree which could be attributed to more high E_e leading to the shift of the radiation maximum to higher E_γ ($\sim E_e^{3/2}$).

Comparison of our results for E_e=1200 MeV (Fig. 2,a and Fig. 2,c) with theoretical calculations of work [2] (Fig. 2,e) shows that continuous model gives more correct description of polarization energy dependence. It should have a broad maximum at E_γ=5-10 MeV with a flattening out at E_γ=20-30 MeV.

At Fig. 2,a and Fig. 2,c the results of theoretical calculations on the base of "thermal-layer" model are shown. Despite the fact that the authors performed this analysis using the parameters very close to ours for electron beam initial energy 1200 MeV, their calculation agree with our experimental data only qualitatively. As it is seen from intensity, this calculation overestimated the coherent effect (i.e. theoretical intensity spectrum is higher than experimental). That, of course, leads to higher polarization, since the polarization value should depend from a number of electrons involved in channeling motion (i.e. in coherent radiation).

The characteristic feature of obtained results is that the beam polarization energy dependence is very similar to intensity energy dependence. To check this suggestion, the polarization in the coherent part of the spectrum was calculated from experimental data according to the formula:

$P_c = ((N_{\|} - N_o) - (N_{\perp} - N_o))/(((N_{\|} - N_o) + (N_{\perp} - N_o))\Sigma)$.

The results of these calculations are given at Fig. 3. It is seen that polarization in the coherent part of the spectrum changes weakly with displacement from maximum of intensity energy spectrum, which proves out conclusion mentioned above.

CONCLUSIONS

Investigated low energy photon beam spectrum, produced by electrons moving in silicon crystal along the crystallographic plane, possesses the peak with the high polarization degree ~80 % whose intensity exceeds approximately in 5-6 times the amorphous level. The "thermal-layer" model, that gives good theoretical description of the experiments with diamond, overestimate the polarization for silicon crystal. The characteristic feature of radiation is that the beam polarization, as a function of photon energy, reflects the behavior of the radiation intensity spectrum itself.

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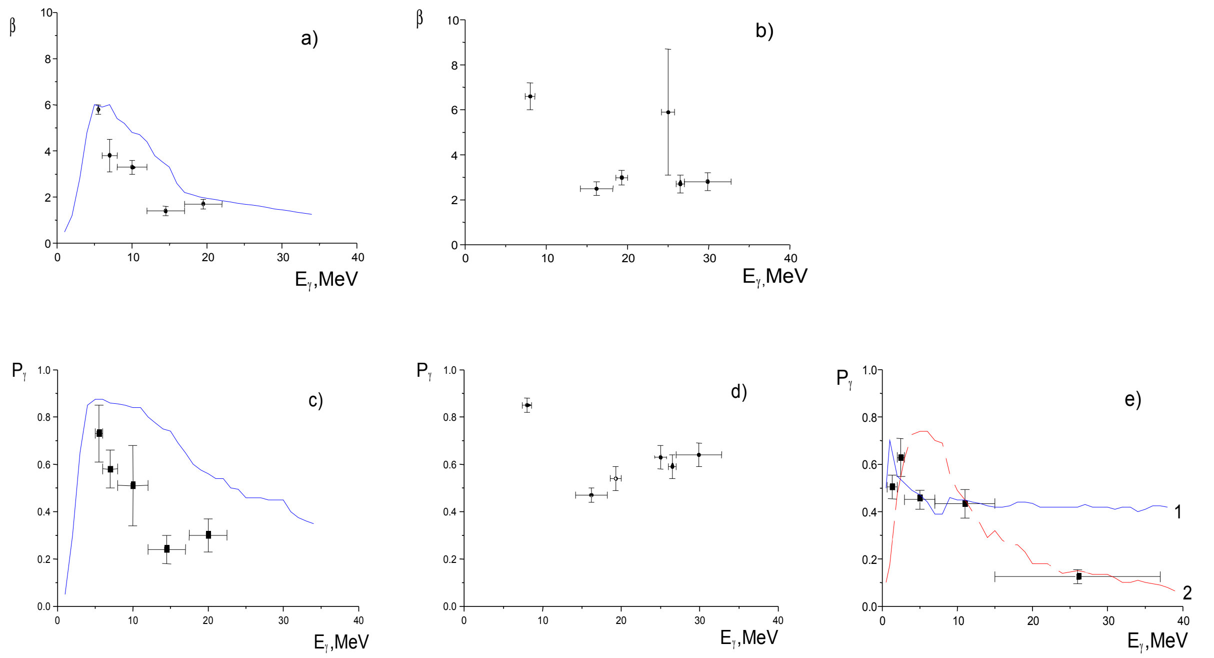

Fig. 2. *Relative intensity and polarization degree of the photon beam.a),c) - E_e=1200 MeV, t=500 μm, curves – results of work [4];b),d) - E_e=1500 MeV, t=290 μm;e) - data of paper [2]: E_e=900 MeV, t=400 μm, (1) - modeling and (2) - continuous model*

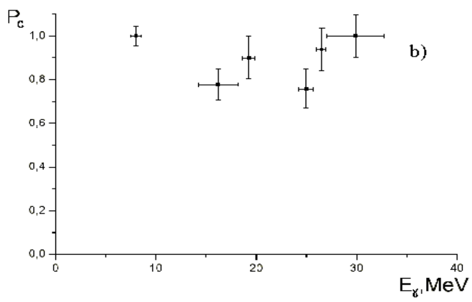

Fig. 3. *Polarization in the coherent part of the spectrum at E_e=1500 MeV, t=290 μm*

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