Monochromatic high-energy γ rays from positron annihilation in single-crystal silicon

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It is shown that the channeling of 1-GeV positrons in a silicon single crystal 300 μ thick changes appreciably the emission spectrum of the channeling positrons in comparison with the emission spectrum of the positrons of an amorphous target: the bremsstrahlung intensity (I_{br}) decreases by a factor of 4.4 and that of the annihilation radiation (I_{annih}) decreases by a factor 1.6, thus increasing the ratio I_{annih}/I_{br} by 2.7 times.

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We have suggested in [1] that the use of a single crystal as an annihilation target to obtain monochromatic γ rays via positron annihilation in flight can offer significant advantages over an amorphous target: 1) It can increase the ratio (I_{annih}/I_{br}) of the annihilation and bremsstrahlung intensities; 2) it can increase I_{annih} by increasing the thickness of the single crystal, while retaining the same degree of monochromaticity.

The basis for this assumption was the observation of channeling of high-energy positrons in single-crystal silicon,[2] which manifests itself both in a decrease (in comparison with an amorphous target) of the cross section for the bremsstrahlung of positrons trapped in the channel,[3] and in the constancy of the angle divergence of the channeling positron;[1] the latter makes it possible, without adversely affecting the degree of monchromaticity of the annihilation radiation, to increase the thickness of the single crystal, and consequently also I_{annih}.

We have investigated experimentally positron annihilation in flight in a silicon single crystal 300 μ thick, at different orientations of the crystallographic axis [111] relative to the direction of the positron beam.

Greatest interest attaches to a comparison of the positron emission spectra for cases when the crystal axis coincides with the direction of the positron emission in the crystal is close to the conditions of emission in an amorphous target).

The investigations were performed with the LUE 2-GeV linear electron accelerator of our Institute.

The experimental setup is shown in Fig. 1. Positrons of 1 GeV energy with energy scatter $\Delta E/E \approx 2\%$ were directed to a single crystal mounted in a goniometer.

The single crystal was oriented by measuring the dependence of the total positron bremsstrahlung energy flux on the angle Ψ between the [111] axis of

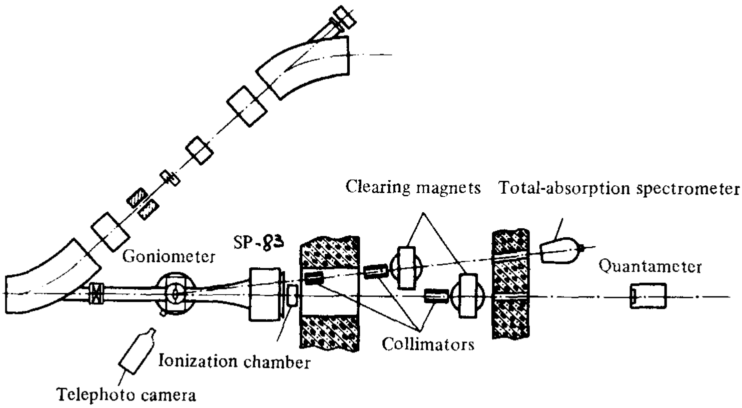

FIG. 1. Experimental setup.

the crystal and the direction of the positron beam. [2]

The bremsstrahlung energy flux was registered with a quantameter, while the γ-ray spectra were measured at an angle $\theta = 2 \times 10^{-2}$ rad with the aid of a Cerenkov total-absorption spectrometer [4] with an energy resolution 13% at 1 GeV. The angle θ was chosen such as to ensure optimal conditions for the observation of the annihilation radiation against the background of the bremsstrahlung. [5]

The measurement results are shown in Fig. 2 as plots of the photons (the number of counts in the pulse-height analyzer channels) N against the γ-ray energy E_γ in MeV.

For a more illustrative comparison of the results, the measurements were performed in such a way that the number of registered γ photons for the histograms 1 and 2 were approximately the same (the areas under the histograms were equal).

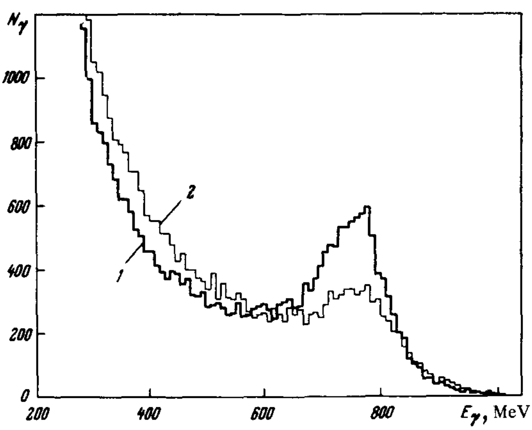

FIG. 2. Spectra of annihilation γ photons for two orientations of the [111] of single-crystal Si relative to the direction of the positron beam: histogram 1—angle $\Psi = 0$; histogram 2—$\Psi = 3 \times 10^{-2}$ rad.

It turned out that the histogram 1, in contrast to histogram 2, corresponds to 3.5 times more positrons passing through the crystal, since the interaction of the channeling positrons with the crystal lattice atoms becomes weaker.

The positron channeling effect leads also, as seen from Fig. 2, to an appreciable change in the emission spectrum of the channeling positrons in comparison with the emission spectrum of the positrons in the amorphous target: the bremsstrahlung intensity decreases by a factor 4.4, while the annihilating intensity decreases by a factor 1.6. As a result, the ratio I_{annih}/I_{br}, one of the principal indicators of monochromatic γ-ray beam quality, is increased 2.7 times.

The width of the annihilation peak is governed principally by the energy resolution of the spectrometer and corresponds to the true width (6%) set by the geometry of the experiment.

Thus, preliminary results of the investigation of the influence of channeling on positron annihilation in a silicon single crystal shows that an increase of the ratio I_{annih}/I_{br} in the crystal, in comparison with the amorphous targets, affords a possibility of obtaining beams of monochromatic quanta with high parameters and of their use in nuclear physics and in high-energy physics.

In conclusion, the authors considered it their pleasant duty to thank V.M. Kozbezskiĭ, V.M. Popenko, and the accelerator crew for providing a positron beam with the required parameters.

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