ORIENTATION EFFECTS IN ULTRARELATIVISTIC ELECTRON TRANSMISSION THROUGH A SINGLE CRYSTAL

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The results of experimental investigations of the 1.2 GeV electron transmission dynamics in a thin single crystal of Si are discussed. The interpretation of the electron scattering orientation dependencies measured under different scattering angles is carried out. The existence of scattering direction, where one can observe the scattering intensity independence on the crystallographic plane orientation is shown. Besides the existence of crystallographic axis orientation, where one can observe the region of uniform angle distribution of scattering intensity, is shown.

INTRODUCTION

Experimental research of the passing dynamics of electrons with the energy about 1 GeV into a crystal represents an interest because the opportunity to use the clearly classical approach for its description [1-3]. On the other hand under such energies the relativistic phenomena manifests brightly in transmission, scattering and radiation processes.

In the present work the results of experimental researches of orientation effects in ultrarelativistic electron scattering in a Si single crystal are presented. The experiments was carried out on LUE-2000 MeV accelerator of NSC "Kharkov Institute Physics and Technology".

The experiments on electron scattering have been carried out by the typical measurement scheme. A single crystal target was housed into evacuated chamber with an goniometer which permits to orient the target in relation to the axis of projectile electron beam with the accuracy of $5\cdot10^{-5}$ radian. The electrons transmitted through target was detected by a diminutive Ge detector (of 0.5x0.5 мм^2 size) situated at a distance of about 15 meters from the target, what corresponds to a solid angle near $1\cdot10^{-9}$ sr. The angle distribution of the scattered particles was measured by the detector scanning the scattered beam in transverse plane. In present work the dependence of the angle flux density distribution of the scattered electrons was measured on the given atomic axis and (or) plane orientation in crystal.

1. TRANSMISSION OF ELECTRONS AT A SMALL ANGLE TO A CRYSTALLOGRAPHIC AXIS

The experimental investigations of the passage of ultrarelativistic electrons through a thin single-crystal target were set up on the 1.2 GeV electron beam. The 10 μm Si monocrystal cut along the (111) plane was used as a target. The incident electron beam was collimated to a diameter of 0.3 mm and had a measured divergence of 10^{-5} radian. By means the detector fixed on the beam axis the orientation dependencies of the scattered electrons transmission was measured. The electron transmission dependence on orientation relative to <111> crystallographic axis is shown in Fig. 1. Here the narrow angle region near direction of the projectile beam axis is shown. The transmission intensity is presented as the ratio to transmission intensity through disoriented target. In the same figure the results of the calculations are presented. A strong scattering effect is manifested at the range of the small angles (forward transmission intensity IΨ << 1). The coherent effects in interaction processes of the fast charged particle with the ordered atomic media manifest most brightly in thin crystals. In this case, a new feature is observed as a local minimum of electron transmission intensity at the range of the small orientation angles, which is similar to well known blocking effect.

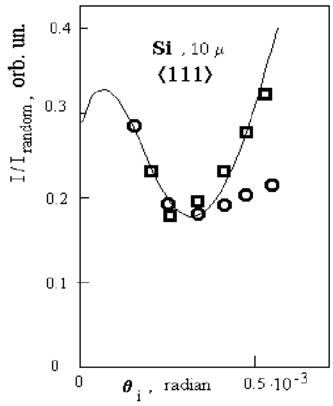

Fig. 1. *The dependence of transmission of 1.2 GeV electrons through 10 μm Si single crystal on <111> axis orientation. Registration solid angle is ~10^{-9} sr. Solid curve denoted the results of the experiment. Circles denote the result of the calculation taking into account only the azimuthal scattering on atomic strings. Squares denote the result of the calculation taking the scattering of electrons on azimuth and polar angle*

Other peculiarity of the measured orientation dependence of forward transmission intensity show the comparison with calculated one in the theoretical model of relativistic electron azimuthal multiple scattering on atom chains in crystal [1].

It turns out that calculation gives significantly more flat transmission intensity dependence on crystallographic axis orientation angle than measured in the experiment (see Fig. 1, circles). The qualitative explanation of this disagreement was provided by taking into account the particle scattering by polar angle, which leads to additional suppression of transmission intensity in the small region of orientation angles [2]. Taking to account of the particle polar angle scattering leads to dependence, shown in Fig. 1 by squares.

The results of the electron transmission (curve 1) and scattering (curves 2-8) intensity measured in a small solid angle at different angles in the plane normal to axis of crystal target rotation are presented in Fig. 2 and Fig. 3. The results presented in Fig. 2 are obtained with the use of the 10 μm Si single crystal as a target on the electron beam of 500 MeV. For comparison in the Fig. 3 are presented a similar results obtained early on the electron beam of 760 MeV under using Si single crystal of 80 μm thickness and significantly worse angular discrimination ($1.2{\cdot}10^{-8}$ steradian).

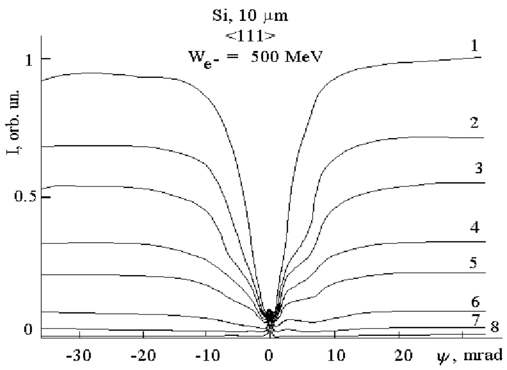

Fig. 2. *The dependence of transmission and scattering of 500 MeV electrons through 10 μm Si single crystal on <111> axis orientation. Registration solid angle is ~10^{-9} sr. The average electron multiply incoherent scattering angle θs =0.15 mrad. The scattering angles θ, mrad: 1 – 0; 2 – 0.08; 3 – 0.12; 4 – 0.16; 5 – 0.18; 6 – 0.23; 7 – 0.27; 8 –0.3*

It is worthy of note that the transmission intensity relation axis to random crystal orientation sharply depends on measure angular discrimination. The relation of electron transmission intensity through a crystallographic axis oriented and disoriented crystal is noteworthy. The typical curve of the transmission intensity dependence *vs* the crystallographic axis orientation has a local maximum (under crystallographic axis aligned along the projectile beam axis, i.e. θ = 0) comparable with the electron transmission intensity through disoriented crystal. But the measure of high angular discrimination gives much lower maximum. This fact is in a close accordance with azimuth multiple scattering concept. As may be seen from the diagrams Fig. 2 and Fig. 3, there is such crystal orientation, which results in confluence of all orientation curves, which is to say that a scattering angle region of uniform intensity distributions is being under this crystal orientation.

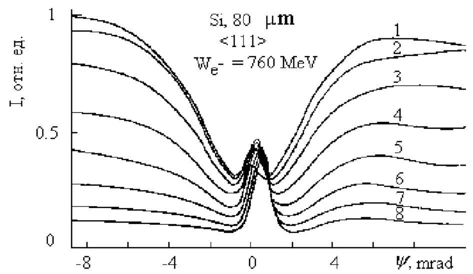

Fig. 3. *The dependence of transmission and scattering of 760 MeV electrons through 80 μm Si single crystal on <111> axis orientation. Registration solid angle is $1.2{\cdot}10^{-8}$ sr. The scattering angles θ, radian: 1 –0; 2-0.17·10-3; 3- 0.34·10-3; 4- 0.51·10-3; 5- 0.65·10-3; 6- 0.80·10-3; 7- 0.89·10-3; 8- 1.03·10-3*

2. ELECTRON PASSING AT SMALL ANGLES TO CRYSTALLOGRAPHIC PLANE

In this section the results of the orientation dependence measurements of the 1200 MeV electron transmission and scattering intensity on (110) atomic planes in 10 μm Si single crystal are presented. The crystal was so aligned (see in Fig. 4) that axis of rotation of crystal in goniometer is in (110) plane of the crystal and both the orientation angles Ψ and observation angles θ lie in plane perpendicular to plane (110). The measurements were carried out by the same scheme and with using the same detector which are described above. The results are shown in Fig. 5. As may be seen from the diagram, electron transmission forward into small solid angle is minimal when crystal is oriented by a crystallography plane along projectile beam axis, i.e. the electron beam passing along the atomic planes are scattered more than one passing at an angle to the planes. It is seen also that in the crystal aligned by an atomic plane along the projectile electron beam the electrons scattering turn out symmetrically to the plane. The intensity of the electron scattering to certain angle θ > θs, (where θs – electron multiple scattering angle in random crystal orientation) in the range of small orientation angles ψ is higher than the in case of strong disorientation of crystal. The maximum intensity position do not coincide with the value of the orientation angle ψ, i.e. orientation dependence became allokurtic (asymmetric) in relation to orientation ψ=0. This effect was observed also by authors of work [4] and was named “quasiscattering effect”. The explanation of this effect was done theoretically as the result of joint action of the incoherent multiple scattering and channeling in work [5].

As may be seen from Fig. 5, the scattering intensity at scattering angle θ*≈θs practically do not depend on crystal orientation, that can be used in measurements for control of beam current.

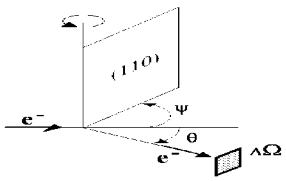

Fig. 4. The geometry of the experiment on orientation dependence of 1200 MeV electron transmission (scattering angle $\theta = 0$) and scattering ($\theta \neq 0$) incident at small angles ψ to crystallographic plane

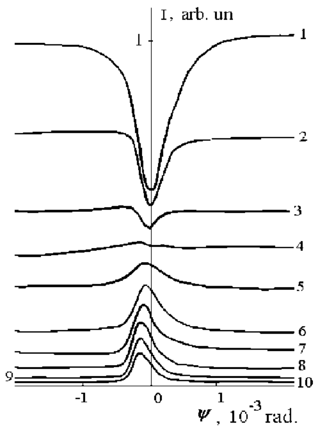

Fig. 5. The dependencies of 1200 MeV electron transmission and scattering in the 10 μm Si crystal into small solid angle $\Delta\Omega = 10^{-9}$ sr vs ψ of (110) plane orientation for the observation (scattering) angles θ: 1-0; 2-0.047; 3-0.067; 4-0.084; 5-0.103; 6-0.13; 7-0.148; 8-0.186; 9-0.231; 10-0.273 mrad

3. ELECTRON FORWARD TRANSMISSION UNDER PLANE CHANNELING CONDITIONS

Such a result obtained by the specific measurements is presented in this paragraph. In preparations for the experiment on the measurements the axis of the crystal rotation was located normal to projectile beam direction axis and crystallographic axis <111> located in plane of crystal rotation. The dependence of electron transmission intensity on crystal rotation angle ψ are shown in Fig. 6 for different values of the orientation angle α between the normal to a crystallographic plane and crystal revolution axis.

The lower curve is in accord with coincidence the atomic plane normal with the crystal rotation axis (α =0). In this case the crystal rotation do not change the position of the atomic plane normal. The "disordered orientation" in this case remains indeed as the plane aligned orientation and related intensity turn out lower then under real disordered orientation (the top curve).

At small α angle value (second and third curves from below) the plane orientation change are observed as a wide trough on the orientation dependence.

CONCLUSIONS

Experimental research of the ultrarelativistic electron transmission and scattering presented in the work displays a row of the most characteristic orientation effects, including such a new effects as blockage of the forward electron transmission, asymmetry of the electron scattering on atomic planes. The obtained result can be applies both to dynamics of the fast charged particles in crystals and to processes tightly bound with dynamics, namely photon radiation processes, pair production, nuclear reaction in crystal.

Fig. 6. The (110) plane manifestation in orientation dependence of 500 MeV electron transmission through thin Si crystal at small angles to <111> axis. The registration solid angle $\Delta\Omega = 10^{-8}$ sr

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