Experimental study of 760 MeV electron scattering by a silicon crystal

D. I. Adeĭshvili, A. P. Antipenko, S. V. Blazhevich, G. L. Bochek, V. I. Vit'ko, V. L. Morokhovskiĭ, and B. I. Shramenko

Khar'kov Physicotechnical Institute, Ukrainian Academy of Sciences
(Submitted 3 October 1986)
Zh. Eksp. Teor. Fiz. **92**, 1574–1577 (May 1987)

The orientation dependences of scattering of ultrarelativistic electrons by a silicon crystal is investigated experimentally. It is shown that coherent effects are manifest only in the azimuthal scattering of the electrons. This confirms the theoretical concept of an annular distribution of the particles scattered by a chain of atoms in the crystal.

The interaction of ultrarelativistic electrons with single crystals has attracted the particular attention of physicists because of the new possibilities of obtaining controlled, narrow, monochromatic radiation beams. However, radiation problems are inseparably connected with the dynamics of electron passage through a crystal, and although at this time a number of experimental (Refs. 1–7) and theoretical (Refs. 8–9) studies have been carried out on this problem, the problems of the transmission and scattering dynamics remain vital. The purpose of this study was an experimental investigation of the orientation dependences of the scattering of ultrarelativistic electrons on silicon crystals. The experiment was carried out on the Khar'kov LUE-2000 linear accelerator.

TECHNIQUE AND EXPERIMENTAL RESULTS

A structural diagram of the experimental setup is shown in Fig. 1. A beam of 760-MeV electrons with a divergence of 2×10^{-4} rad and transverse dimensions of 8 mm is formed at the accelerator exit.[1] This beam is then directed to a silicon crystal 80 μm thick oriented with the $\langle 111\rangle$ axis along the beam and installed in goniometer 3. Part of the beam passing through the crystal was cut out by collimator 5 having a diameter of 1 mm, passed through the exit foil of the electron guide 6 and through collimator 7 having a diameter of 2 mm, and was recorded by ionization chamber 8. The signal of ionization chamber 8 was amplified and applied to an automatic plotting *x-y* potentiometer, to the second input of which an electric voltage proportional to the deflection angle of the crystal was simultaneously applied. By means of the electromagnetic correcting devices 2 and 4 installed near the goniometer it was possible to deflect the beam from its original direction, setting thereby the angle at which the orientation dependence of the scattered-electron current was observed. Correcting device 4 was set in such a fashion that the beam was deflected in the plane in which the disorientation of the crystal was created, while correcting device 2 deflected the beam in the perpendicular plane. By the use of electromagnetic correcting devices it was possible to vary the angle at which the scattered electrons were recorded without changing the position of the recording channel. The correcting devices were calibrated by two methods: by measuring the beam displacement on a fluorescent screen placed in the path of the beam, and by measuring the electron current entering ionization chamber 8 through the disoriented crystals.

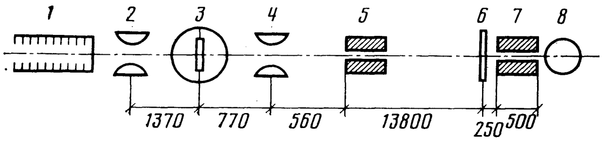

FIG. 1. Block diagram of the experiment: 1—exit from accelerator LU-2000; 2 and 4—electromagnetic correcting devices; 3—goniometer with crystal; 5—collimator of 1 mm diameter; 6—exit aluminum foil; 7—collimator of 2 mm diameter; 8—ionization chamber. The dimensions are indicated in mm.

In the second case the measured distribution of the electron-beam current was approximated by the function:

$$I=I_0\exp(-\theta^2/\theta_\omega^2), \qquad (1)$$

where θ_ω is the root-mean-square scattering angle calculated from the Moliere formula (Ref. 10); I_0 is the value of the electron current through the recording channel with the electromagnetic correcting device turned off. The corresponding angle of beam deflection by the electromagnetic correcting device was calculated from Eq. (1):

$$\theta=\theta_\omega[-\ln(I/I_0)]^{1/2}.$$

By the use of this technique we were able to obtain detailed information on the orientation dependence of the current of the electrons scattered in the crystal at various angles over the range from 0 to 10^{-3} rad.

The experimental family of curves for the orientation dependence of the current of electrons scattered by the crystal in a plane coinciding with the plane in which crystal disorientation was carried out, is shown in Fig. 2. The scatter-

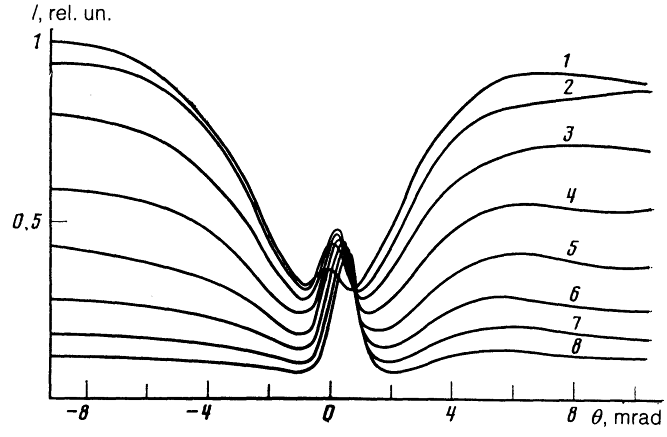

FIG. 2. Measured dependences of the current of electrons scattered in a plane set by the direction $\hat{n}$ of the incident electron beam on the crystal and by the crystal axis $\langle 111\rangle$, as a function of the orientation angle of the Si crystal axis $\varphi = \measuredangle(\hat{n},\langle 111\rangle)$ for various scattering angles θ, rad: 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}.

0038-5646/87/050882-02$04.00

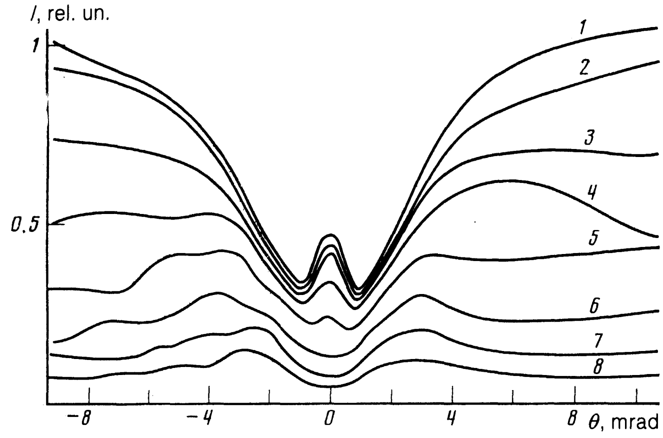

FIG. 3. Measured orientation dependences of electron scattering by an Si crystal of 80 μm thick in a plane perpendicular to the plane set by the direction n of the incident electron beam on the crystal and by the $\langle 111 \rangle$ crystal axis, for various scattering angles θ in rad: 1—0; 2—0.30×10^{-3}; 3—0.5×10^{-3}; 4—0.65×10^{-3}; 5—0.9×10^{-3}; 6—1.2×10^{-3}; 7—1.5×10^{-3}; 8—1.76×10^{-3}.

ing angle was set by bending the beam with the electromagnetic correcting device 4 (see Fig. 1). Curve 1 corresponds to the orientation dependence of the forward passage of electrons through the crystal within the limits of a solid angle set by the recording channel, equal in our case to 1.2×10^{-8} sr. It has the shape typical for this dependence. All subsequent curves of the family correspond to a current of electrons scattered at a given angle. As is evident from the figure, these curves have a characteristic maximum, whose position is shifted with respect to the maximum of curve 1 by an angle equal to half of the corresponding angle of beam bending (scattering angle).

Figure 3 shows the family of curves for the orientation dependence of the current of electrons scattered by the crystal in a plane perpendicular to the disorientation plane of the crystal axis $\langle 111 \rangle$. The angle of electron scattering was set by bending the beam with correcting device 2. In this case the maximum, which is observed on the curves of the orientation dependence of the scattered electron current, does not change its position with change of the scattering angle, but the current at the maximum declines rapidly with increase of the scattering angle. It is necessary to note that the orientation dependence of the current of electrons scattered to the recording channel takes place at disorientation angles greater than the characteristic Lindhard angle (4.7×10^{-4} rad) and the multiple-scattering angle (7.96×10^{-4} rad).

DISCUSSION OF RESULTS AND CONCLUSIONS

The shift of the maxima on the experimental curves of the orientation dependence of the scattered electrons (see Fig. 2), by an angle, equal to half of the corresponding scattering angle, agrees with the premise that particles multiply scattered by chains of atoms have an annular distribution (Ref. 8).

Approximating the experimental angular distributions of electrons scattered in the plane set by the direction of the incident beam on the crystal n and the crystal axis $\langle 111 \rangle$ by a Gaussian function, we observed no dependence of the width of the distribution on the orientation angle $\varphi = \sphericalangle(n, \langle 111 \rangle)$ of the crystal axis in the region of values $|\varphi| > 1.5$ mrad. From this it can be concluded that at these orientations of the crystal axis coherent effects are manifested only in the azimuthal scattering of the electrons.

Measurements of the background conditions of the experiment showed that for crystal-axis orientation angles $|\varphi| > 1$ mrad the contribution of gamma radiation from the crystal to the ionization-chamber signal did not exceed 3%. At angles $|\varphi| \leqslant 1$ mrad this contribution increases, and reaches 30% at $\varphi \approx 0$. In this case it is necessary to correct, in electron-scattering investigations, for the gamma radiation background or to use a detector which is not sensitive to gamma radiation.

The proposed technique of experimentally investigating the passage and scattering of ultrarelativistic electrons through a single crystal, by means of which it was possible to obtain detailed information about the orientation dependences of these processes, can successfully be used to clarify various features of the dynamics of electron passage through a crystal.

[1] I. A. Grishaev, V. L. Morokhovskiĭ, and B. I. Shramenko, Proceedings, 5th All-Union Conference on the Physics of the Interaction of Charged Particles with Single Crystals, Moscow University Press, 1974, p. 282.
[2] V. L. Morokhovskiĭ and B. I. Shramenko, Proceedings, 7th All-Union Conference on the Physics of the Interaction of Charged Particles with Single Crystals, Moscow University Press, 1976, p. 173.
[3] H. Kumm, F. Bell, R. Sizman, H. I. Reiner, and D. Harger, Rad. Eff. **12**, 53 (1972).
[4] V. V. Kudrin and S. A. Vorobiev, Rad. Eff. **21**, 119 (1975).
[5] U. Schiebel, A. Neufert, and G. Clausnitsev, Phys. Lett. **1217**, 45 (1972).
[6] G. L. Bochek, V. I. Vit'ko, V. B. Ganenko, *et al.*, Ukr. Fiz. Zh. **30**, 1246 (1985).
[7] V. I. Kasilov, N. I. Lapin, V. I. Truten', and N. F. Shul'za, Abstracts, 16th All-Union Conference on the Physics of Interaction of Charged Particles with Crystals, Moscow University Press, 1986, p. 84.
[8] V. I. Truten', S. P. Fomin, and N. F. Shul'za, Preprint 82-11, Khar'kov Physicotechnical Institute, 1982, p. 28.
[9] A. I. Akhiezer and N. F. Shul'ga, Usp. Fiz. Nauk **137**, 561 (1982) [Sov. Phys. Usp. **25**, 541 (1982)].
[10] G. Moliere, Z. Naturforsch. **3a**, 78 (1948) and **3a**, 177 (1955).

Translated by S. J. Rimshaw