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A STUDY OF HIGH-ENERGY ELECTRON MOTION THROUGH MONOCRYSTALS USING SECONDARY ELECTRON EMISSION

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Abstract   Dechanneling lengths of ultrarelativistic electrons in a silicon crystal have been measured. The dechanneling process has been studied by measuring the yields of a secondary high-energy component of electron emission from crystals with channeled and random orientations as functions of a crystal thickness. For 1200MeV electrons (the [111] axis) the dechanneling length is found to be $39 \pm 4\ \mu m$, and $28 \pm 5\ \mu m$ – for electrons channeled in the $(1\bar{1}0)$ plane. The analysis of the experimental data gave the number of particles captured in axial channeling to be ~14%, and about 24% for planar channeling at an initial beam divergence of $2 \cdot 10^{-4}$ rad.

Key words: monocrystal, electrons, GeV-range 1-10 GeV, dechanneling

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INTRODUCTION

It is known that electrons with an initial momentum vector making an angle with the crystal axis or plane smaller than the critical angle of channeling are captured into the channeling regime[1]. During motion the channeled particles may become dechanneled mainly due to scattering on atoms and electrons. The investigation of secondary processes such as the scattering of primary particles and knocking-out of secondary ones, allows one to determine dechanneling lengths and the number of channeled particles.

In this paper we report the first measured dechanneling lengths of ultrarelativistic electrons (the thickness over which the number of channeled particles decreases by e times) and the obtained number of channeled particles as a function of thickness.

EXPERIMENTAL RESULTS

Previous studies of electron emission from monocrystals [2-4] have shown that the yield of secondary high-energy electrons ($E > 300$ eV) depends on crystal orientation and is determined by elastic collisions of initial electrons with target electrons. The characteristic impact parameter value is smaller than the interatomic distance in the crystal. For our experiment we have chosen silicon monocrystals cut out perpendicular to the [111] crystal axis with thicknesses 8, 30, 80, 180, 250, 460 and 920 μm. The procedure of secondary emission measurements from single crystals has been described in paper [3].

The dependence of high-energy electron emission per incident electron on the thickness of a single crystal with random orientation at an initial electron energy of 1200 MeV is shown in Figure 1. A least-squares-determined curve $\delta(t) = 2.8 \cdot 10^{-3} \cdot t^{0.4}$ is drawn across the experimental points. The approximation factors are close to the values predicted theoretically in paper [5].

The difference between emission yields from a crystal with channeled and random orientations, $\Delta(t)$, for the (110) plane (see Figure 2a) and the [111] axis (Figure 2b) grows exponentially until Δ_m with the crystal thickness increasing until ~100 μm.

As the crystal thickness increases in the range where channeled particles exist, the total emission yield grows, i.e., for each crystal thickness where

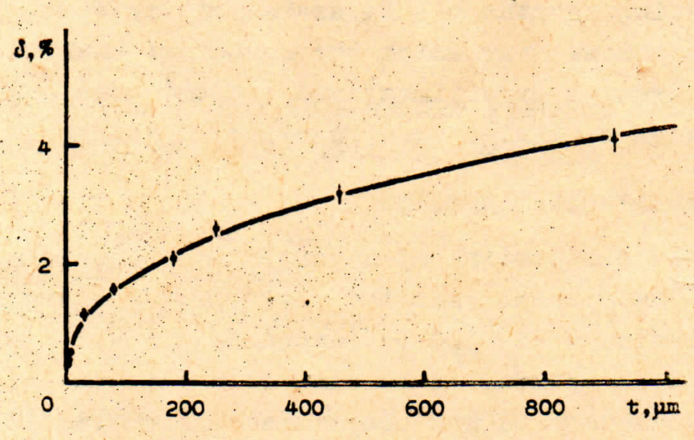

FIGURE 1 Yield of high energy emission from a crystal with random orientation.

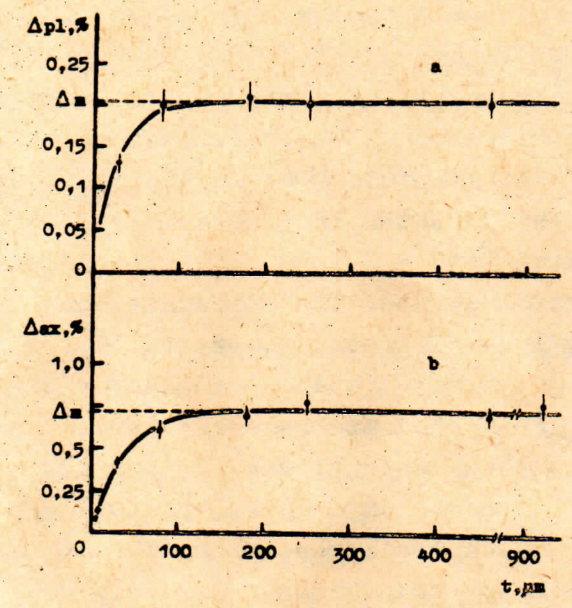

FIGURE 2 The function Δ(t) for the plane (a) and the axis (b).

there are channeled particles, the increase of $\Delta(t)$ is contributed by these particles. The growth rate of this contribution decreases with the thickness increase because the fraction of channeled particles is reduced. At a certain crystal thickness where all the particles have become dechanneled, $\Delta(t)$ reaches its highest value and remains constant with the thickness increase until the secondary electron absorption is low.

DISCUSSION

Dechanneling Lengths

We assume that the dependence of the number of channeled particles on a thickness has a form

$$\alpha_c(t) = \alpha_0 \cdot EXP(-t/\lambda) , \qquad (1)$$

where α_0 is the number of particles captured in the channeling regime, λ is the dechanneling length. Then the yield difference for the crystal with channeled and random orientations depends on the crystal thickness as

$$\Delta(t) = \Delta_m \cdot [1 - EXP(-t/\lambda)] \qquad (2)$$

The solid curves in Figure 2 show the approximation of the experimental points by the least-squares technique using this formula. The dechanneling length of 1200 MeV electrons in the planar (110) channel of a silicon crystal is 28 ± 5 μm which is in agreement with a theoretical value given in paper [6]. The dechanneling length in the [111] axial channel equals 39 ± 4 μm. This value is close to a calculated value of 34 μm. Thus, the experimental results confirm the main statements of a theory of dechanneling [7].

Number of Channeled Particles

The data presented here allow one to estimate the number of particles captured into the crystal channel, α_0.

The yield of a high-energy component of the electron emission (E, E_n) from a random crystal can be written as

$$\delta_{rand} = \int_0^t d\tau \int_{E_n}^{E_m} dE \cdot \Sigma(E) \cdot \mu(t-\tau, E) \cdot \bar{\rho} \quad , \qquad (3)$$

where $\bar{\rho}$ is the mean electron density, t is the crystal thickness, Σ is proportional to the macroscopic cross section for primary-particle scattering on the electrons of the matter, E_m is the maximum energy of secondary particles, μ describes the absorption of the secondaries.

In the description of the yield of the high energy component of the emission from the channeled crystal it is necessary to make the substitution in Eq.(3):

$$\bar{\rho} \to \alpha_c(\tau) \cdot \rho_c + [1 - \alpha_c(\tau)] \cdot \bar{\rho} \quad , \qquad (4)$$

where $\alpha_c(\tau)$ is the number of channeled particles at a depth τ, ρ_c is the mean electron density in the channel. From Eqs.(3) and (4) we obtain the difference between the yields from channeled and random crystals:

$$\Delta(t) = (\rho_c - \bar{\rho}) \cdot \int_0^t d\tau \cdot \alpha_c(\tau) \int_{E_n}^{E_m} dE \cdot \Sigma(E) \cdot \mu(t-\tau, E) \qquad (5)$$

The inner integral in Eq.(3) is replaced by its average value in the region where α_c is non-zero, i.e., in the thickness range $0 - 3\lambda$

$$\left\langle \int_{E_n}^{E_m} dE \cdot \Sigma(E) \mu(t-\tau, E) \right\rangle = \frac{\delta_{rand}(3\lambda)}{3\lambda \cdot \bar{\rho}}$$

Using Eq.(1) for the dependence of the number of channeled particles on the thickness, we obtain Eq.(2) for the difference between the yields of high energy emission from the crystal with channeled and random orientations, and in this case

$$\Delta_m = \frac{\rho_c - \bar{\rho}}{\bar{\rho}} \cdot \frac{\delta_{rand}(3\lambda)}{3} \cdot \alpha_0 .$$

Using the Lindhard equation [1] for the electron density in an atom for a silicon crystal, we obtain $(\rho_c - \bar{\rho})/\bar{\rho} = 8$ - the [111] axis and $(\rho_c - \bar{\rho})/\bar{\rho} = 1.5$ - the (110)plane.

Here we assumed that in the axial case the particles are channeled in a tube with a radius equal to the screening radius, while in the planar case, the particles are channeled in the plane with a width equal to two screening radii.

It follows from the data obtained that the fraction of the particles captured in axial channeling is 0.14 and that - in planar channeling is 0.24. The calculations of the number of particles captured in channeling using the data of paper [8] for a beam divergence of $2 \cdot 10^{-4}$ rad give 0.12 for the [111] axis and 0.18 for the (110)plane,which is in good agreement with experiment.

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