DIRECTIONAL EFFECTS IN ALBEDO AND ANGULAR DISTRIBUTIONS OF RELATIVISTIC ELECTRONS REFLECTED FROM SINGLE CRYSTALS AT GRAZING INCIDENCE

S.V. Dyuldya*

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine

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Using the computer experiment methods directional effects of relativistic electrons' coherent reflection from crystal surface at glancing incidence were studied in conditions when it is due to multiple transversal scattering of particles by atomic chains (axial surface channeling). Directional dependencies of backscattering coefficients, ranges and depths of reflected electrons' penetration in crystal and their angular distributions have been calculated. It has allowed to elicit the directional effects of strings that lead to reflection at grazing angles close to the beam incident angle with respect to atomic chain as well as kinetic effects of surface plane that result in specular reflection and dominate at large beam misalignments with respect to low-index crystallographic directions.

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It is well known that at grazing incidence of swift charged particles on a crystalline surface at small angles with respect to major crystallographic directions the directional effects of crystal orientation are observed. They are due to correlations of particle collisions with atoms of surface atomic chains. These collective correlated (or coherent) reflection mechanisms are well-studied for ions [1] and result in specific features of energy spectra and angular distributions of reflected particles (ion focusing, semichanneling and surface channeling).

Similar mechanisms of coherent reflection are expected to take place also for relativistic electrons and positrons although currently no experimental data for high energy region are available and the investigations are limited with theoretical estimations and modeling [2, 3, 4, 5]. The significance of these studies along with fundamental value of investigations of new mechanisms of particle-surface interactions is determined by the opportunity of their application for high energy beams control [6].

From this point of view the mechanisms of coherent reflections of relativistic electrons are of the greatest interest. Due to negative charge of electrons at highly relativistic energies they differ from those for positive ions or positrons. In particular the negative charge prohibits their coherent specular reflection from the surface plane [1, 6], the planar surface semichanneling.

In Ref. [2] we had proposed the mechanism of reflection of electrons from single crystal surfaces that is due to azimuthal coherent scattering of particles by an atomic chain (the axial surface semichanneling). The backscattering coefficient (albedo) had been calculated at angles θ with respect to axial direction less then the critical angle θ_a of axial channeling (Lindhard angle).

For small $\theta \ll \theta_a$ even single azimuthal scattering by atomic chain leads to high efficiency of coherent reflection [2]. However as the grazing angle approaches the Linhdard angle the efficiency of the axial semichanneling mechanism rapidly decreases and the effects of multiple scattering by atomic strings [7, 8] (the axial surface channeling) become important [4].

The theoretical investigation of coherent reflection of electrons at axial surface channeling was carried out in Ref. [5] by means of computer simulation methods for broad range of grazing angles of beam incidence. The modeling results have been interpreted within the scope of the phenomenological diffusion model based on the assumption of rapid isotropization of the flux of above-barrier electrons in the axial surface channel transversal plane at multiple coherent scattering by atomic chains.

In the present paper in order to complete the picture of directional effects at coherent reflection from axial surface channels the directional dependencies of its integral and differential characteristics are studied as functions of the crystal target tilt and rotation angles.

1. PROBLEM SETUP

Considered is the glancing incidence of a collimated beam of swift electrons with energy E onto an ideal surface of a single crystal plate of length L at grazing angle $\psi_{in} \ll 1$ to surface plane and the

*Corresponding author. E-mail address: sdul@kipt.kharkov.ua

azimuthal angle $\vartheta_{in} \ll 1$ between the beam axis surface projection and the direction of one of low-index crystallographic axes (see Fig.1,a).

Both ψ_{in} and ϑ_{in} are assumed to be small enough so that the angle $\theta_{in} = \sqrt{\psi_{in}^2 + \vartheta_{in}^2}$ between the beam axis and the atomic chain is of order of magnitude of Lindhard angle $\theta_a = \sqrt{2U_a/E}$ where $U_a = 2Ze^2/d$, Z is the crystal atomic number, d is the chain interatomic distance. The initial transversal projection of the beam axis forms the azimuthal angle $\phi_{in} = \arctan(\psi_{in}/\vartheta_{in})$ with the surface plane (see Fig.1,b).

For highly relativistic energies at angles $\theta_{in} < 10^2 \cdot \theta_a$ the coherent interaction of electrons with atoms of chains is described by the averaged continuum potential $U(\mathbf{r})$ of the axial channel that depends only on 2D vector $\mathbf{r}(x, y)$ of the particle's transversal coordinates. In the first approximation the longitudinal motion of particle is free, only the transversal coherent scattering of particles occurs and their transversal energy is conserved. Thus in the axial case the dynamics the particles surface channeling is *per se* two-dimensional. The longitudinal coordinate $z = v_{\|} \cdot t$ is in the first approximation proportional to the time t of coherent interaction.

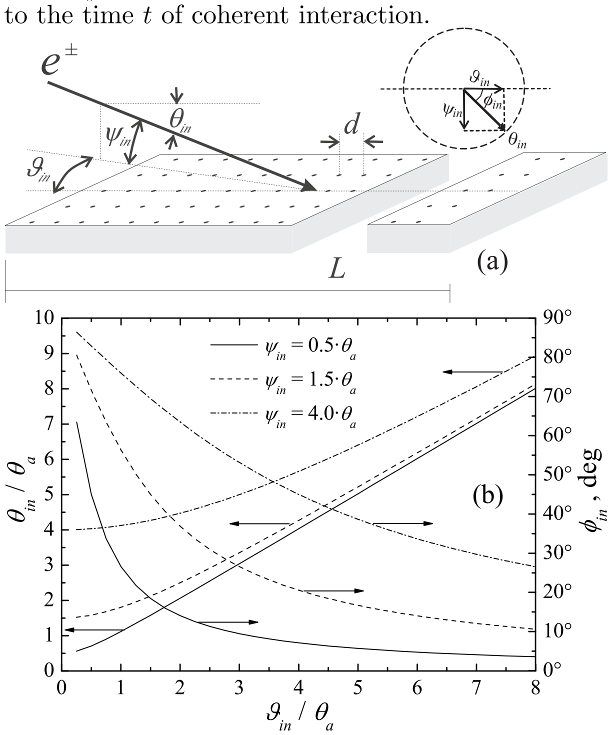

Fig.1. *The geometry of a beam glancing incidence onto a crystal surface (a) and the geometrical interrelations between different angles of a beam axis orientation with respect to a surface and to the close-packed atomic chain (b)*

By definition, the coherent reflection events occur when at such interaction electrons trajectories cross the surface plane $y = 0$ and exit the crystal at emergency angles ψ_{out} with respect to the plane and ϑ_{out} between the surface projection of emergency direction and the crystallographic axis. If total energy losses are neglected the emergency angle with respect to the axis is conserved in view of the conservation of transversal energy $E_\perp$:

$$\theta_{out} = \sqrt{\psi_{out}^2 + \vartheta_{out}^2} \cong \theta_{in}. \qquad (1)$$

The problem consists in the calculation of integral coherent reflection coefficient R for the plate of length L as a function of incident angles ψ_{in} and ϑ_{in}. Also of interest are the differential characteristics of reflection such as angular distributions or the distributions of emergency points over the longitudinal coordinate z (the reflection length distributions). Energy dependencies of these characteristics are universal because the equations of transversal motion indicate that for coherent interaction all these quantities depend only on the ratios ψ_{in}/θ_a and ϑ_{in}/θ_a. Thus the dependency of, e.g., $R(\psi_{in}/\theta_a, \vartheta_{in}/\theta_a)$ can be easily scaled to the dependency $R(\psi_{in}, \vartheta_{in})$ for any value of Lindhard angle $\theta_a \propto E^{-(1/2)}$.

To solve the problem the approach of Ref. [5] is used. This publication contains the detailed description of the applied statistical modeling method and code.

Transversal trajectories of surface channeling are modeled as the sequences of binary collisions of particles with atomic strings till the reflection event takes place or the plate length L is passed. The collisions are assumed to be uncorrelated, so the ordered structure of the channel's transversal plane is neglected.

Since the specific goal of this work consists in the investigation namely of the coherent mechanism of reflection we knowingly ignore in our model the effects of incoherent scattering of particles by atomic thermal vibrations and crystal electrons as well as the total energy losses due to ionization and radiation stopping and the incident beam divergence effects (all of them will be studied in future).

In Ref. [5] we limited ourselves with the degenerated case $\vartheta_{in} = 0$ when the beam axis lays in the plane orthogonal to the surface plane. It corresponds to the normal transversal incidence ($\phi_{in} = 90°$) when the characteristics of coherent reflection depend only on grazing angle ψ_{in}. In this case the coherent reflection requires the multiple transversal scattering by angles $\Delta\phi \approx \pi$.

However unlike for the conventional incoherent reflection the directional effects of coherent reflection are not limited with the dependence on ψ_{in}. The presence of the preferential direction of close-packed atomic chain has to result in the dependencies of reflection characteristics on the azimuthal crystal rotation angle ϑ_{in}. Only the united description of these dependencies describes the effect in whole. Small ratios of angles ψ_{in} and ϑ_{in} correspond to oblique direction of the incident transversal momentum (down to the grazing transversal incidence; see Fig.1,b). At fixed ψ_{in} the increase of ϑ_{in} also results in the increase of the total angle θ_{in} with respect to the axis and, hence, to the increase of $E_\perp \propto \theta_{in}^2$.

To study directional effects we varied both ψ_{in} and ϑ_{in} angles in two ways. In the first one the definite constant transversal energy $E_\perp$ was maintained and the incident angle ϕ_{in} was altered from normal ($\phi_{in} =\ 90°$) to grazing ($\phi_{in} \to 0°$) incidence in the transversal plane. Another way adequately reproduces experimental setups when crystals are rotated by the angle ϑ_{in} at constant ψ_{in}; thus θ_{in} and $E_\perp$ increase while ϕ_{in} decreases.

Similar to Ref. [5] the model case of reflection of a narrow beam of 5.43 GeV electrons from the {011} surface of 1 cm long and 1 mm thick Silicon plate was considered. Electrons experienced the coherent interaction with ⟨001⟩ atomic chains that was described by continuum potential in the Moliere approximation at temperature 300 K. Typical statistics of Monte Carlo modeling was about 10^4 of particle histories that has provided the integral statistical uncertainties less then 1%.

2. INTEGRAL REFLECTION PARAMETERS

2.1. COHERENT REFLECTION PROBABILITY

As it can be seen from Fig.2,a at fixed transversal energy of electrons the total albedo R of coherent reflection increases as ϕ_{in} decreases. The rate and the relative growth of $R(\phi_{in})$ are greater at larger θ_{in} (and $E_\perp$).

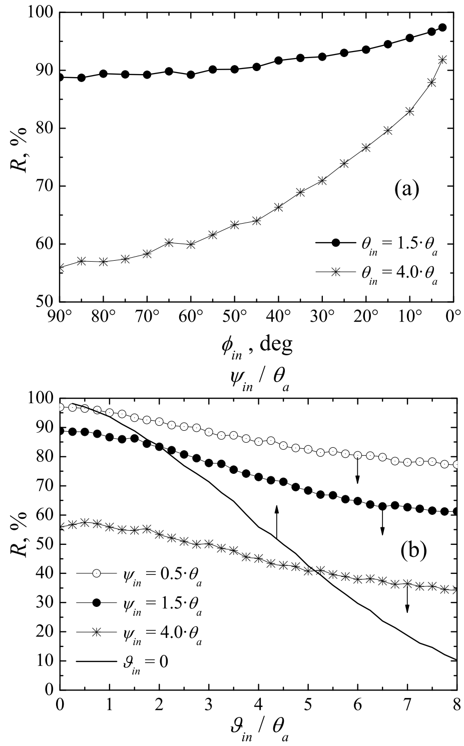

Fig.2. *The directional dependencies of total albedo R of coherent reflection upon the angle ϕ_{in} of transversal incidence at fixed initial transversal energy (a) and on the azimuthal crystal rotation angle ϑ_{in} at fixed grazing angles ψ_{in} (b). For comparison the dependency $R(\psi_{in})$ at $\vartheta_{in} = 0°$, $\phi_{in} = 90°$ [5] is also depicted*

This effect discovers the close analogy of reflection mechanisms between the conventional incoherent backscattering of particles from amorphous media and the coherent reflection subject to the fact that the latter one is determined by the scattering in the transversal space.

In fact, in the transversal plane the angle ϕ_{in} has the meaning of a grazing angle of particle incidence. Its reduction facilitates the reflection of the beam fraction coherently scattered toward the surface plane (for its reflection the scattering by angles $\Delta\phi \sim \phi_{in}$ is required). The reflection probability approaches unity at conditions of grazing transversal incidence $\phi_{in} \to 0°$. Therefore the observed effect is similar to the enhancement of conventional incoherent reflection at grazing incidence that is more pronounced at higher energies of particles [1].

The above-mentioned factor also substantially affects the azimuthal dependencies of coherent reflection probability on the angle ϑ_{in} with respect to the axial surface channel direction at fixed grazing angle ψ_{in}. In Fig.2,b they are compared with the dependency $R(\psi_{in})$ at conditions of normal transversal incidence: $\vartheta_{in} = 0°$, $\phi_{in} = 90°$ [5]. In the latter case the increase of ψ_{in} up to $8 \times \theta_a$ reduces the coherent reflection coefficient by one order of magnitude because the growth of transversal energy effectively prohibits the reflection when it requires the transversal backscattering by angles $\sim \pi$. As ϑ_{in} increases the transversal energy is also increased (and particles have the opportunity to sink deeper into the plate) but again the correspondent reduction of ϕ_{in} facilitates the coherent reflection. These two competitive factors (among which the growth of $E_\perp$ is dominant) form weaker dependency $R(\vartheta_{in})$ that in the same range of transversal energies reduces only by 20...40%.

2.2. COHERENT REFLECTION LENGTH

Other descriptive integral parameter of coherent reflection is the mean length $\langle z\rangle$ that particles travel in the longitudinal direction of a plate till the reflection occurs.

It determines the reflected electrons' life time in a crystal and therefore at grazing incidence has the meaning of the effective crystal thickness for all secondary processes of interaction (e.g. for coherent electromagnetic radiation) [5].

The directional dependencies of $\langle z\rangle$ are depicted in Fig.3 and the details of their forming are illustrated by histograms of the reflection probability distributions over z shown in Figs.4 and 5.

As it can be seen from Fig.3,a,b the transition to the grazing transversal incidence sharply reduces the mean length of coherent reflection. The degree of reduction increases with the increase of transversal energy. It means that even at very large transversal energies the beam fraction that reflects at small ranges in crystal appears as the angle ϕ_{in} decreases.

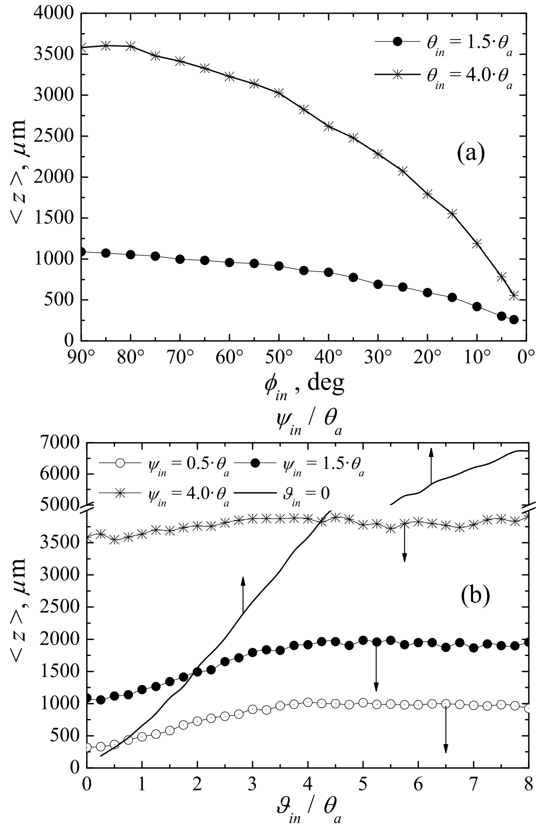

Fig.3. *Directional dependencies of mean length $\langle z \rangle$ of coherent reflection at the same modeling conditions that those of Fig.2,a,b*

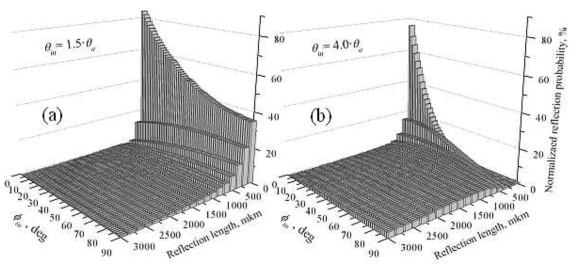

Fig.4. *The distributions $f_z(z)$ of coherently reflected electrons over the reflection length z as functions of transversal azimuthal angle ϕ_{in} at different $E_\perp$*

The existence of such a fraction is observed in differential distributions shown in Fig.4. At $\theta_{in} = 1.5 \cdot \theta_a$ it is tracked even at normal transversal incidence: $\phi_{in} = 90°$. However for this case it is completely absent at $\theta_{in} = 4 \cdot \theta_a$ where the broad maximum of the distribution function ranges to large reflection lengths. As ϕ_{in} decreases the more particles are reflected at small z. For $\theta_{in} = 4 \cdot \theta_a$ even the threshold effect occurs: the distribution function maximum sharply shifts to the region of small z at $\phi_{in} = 50° - 40°$.

The directional dependencies of $\langle z \rangle$ on angles ϑ_{in} and ψ_{in} depicted in Fig.3,b demonstrate the somewhat unexpected saturation effect. Unlike for the normal transversal incidence ($\vartheta_{in} = 0°$) where the rapid increase of $\langle z \rangle$ occurs [5] the azimuthal dependencies of mean reflection lengths saturate at $\vartheta_{in} \sim (3 \dots 4) \cdot \theta_a$ and practically do not depend on ϑ_{in} up to $\theta_{in} = 8 \cdot \theta_a$, the upper limit of the modeled azimuthal misalignments. Because the total coherent reflection probability $R(\vartheta_{in})$ is nevertheless decreasing within this range of ϑ_{in} (see Fig.2,b) it means that a kind of complex compensative effect takes place: the rapid increase of population of particle fraction having small reflection lengths competes with the rapid growth of reflection length for those particles that have the chance to sink deeply in a plate and substantially contribute to $\langle z \rangle$ due to large z values.

The normalized distribution over reflection lengths:

$$f_z(z) = \frac{1}{R(L; \psi_{in}, \vartheta_{in})} \cdot \frac{dR(z; \psi_{in}, \vartheta_{in})}{dz} \qquad (2)$$

at large angles ϑ_{in} of beam misalignment with respect to the surface channel axis direction is weakly dependent on ϑ_{in} (see Fig.5,b-d). This fact agrees with the effect of $\langle z \rangle$ saturation and is satisfied if $R \propto R_1(\vartheta_{in}) \cdot R_2(L)$.

Therefore in this case the properly directional (that depends on ϑ_{in}) and the kinetic (that depends on L) components of coherent reflection probability R are effectively factorized. As now it has to be considered as a fact observed in computer experiment because we have not found a simple qualitative explanation of this feature.

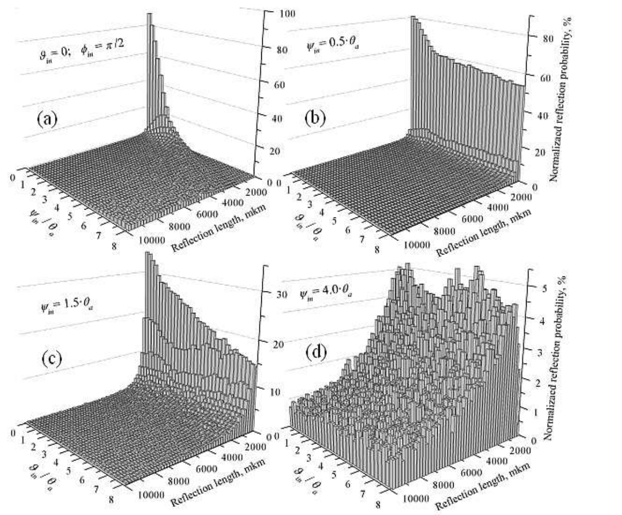

Fig.5. *The distributions $f_z(z)$ of coherently reflected electrons over the reflection length z at normal transversal incidence (a) and as functions of crystal rotation angle ϑ_{in} at various fixed grazing angles ψ_{in} (b–d)*

2.3. COHERENT REFLECTION DEPTH

Similar directional effects have been found for another integral characteristic of coherent reflection, the mean reflection depth $\langle y \rangle$ defined in Ref. [5] as an averaged over all reflected particles maximal depth y that each particle has reached in the near-surface layer of a crystal plate before the reflection event. This quantity describes the lateral thickness of a crystal layer that contributes to the particles backscattering.

The directional dependencies of $\langle y \rangle$ and the distributions of reflected electrons over maximal depth y are shown in Figs. 6 to 8. The behavior of the $\langle y \rangle$ directional dependencies and the distributions over y are quite similar to those observed for the reflection length z (though evidently the range of y is much smaller then that of z; rough estimation shows that $\langle y \rangle \sim \langle z \rangle \cdot \theta_{in}$).

Hence we should only notice that similar saturation of $\langle y \rangle$ at large ϑ_{in} is observed as well as the stationary behavior of normalized distribution functions $f_y(y)$ that become independent on the crystal rotation angle ϑ_{in}.

3. ANGULAR DISTRIBUTIONS OF COHERENTLY REFLECTED ELECTRONS

From the point of view of the investigation of mechanisms and kinetics of coherent reflection the angular distributions of backscattered relativistic electrons are of great interest because they can be measured experimentally.

Basing on modeling data we have calculated the normalized distributions of reflected particles over grazing emergency angles ψ_{out} with respect to the surface plane and over azimuthal angles $\phi_{out} = \arctan(\psi_{out}/\vartheta_{out})$ in the transversal space of a surface channel.

Concerning the azimuthal distributions the basic effect that has been found in modeling consists in the transition from the symmetric distribution for normal transversal incidence to drastically asymmetric distributions for oblique and grazing directions of initial transversal momentum of electrons. This effect is observed at the increase of the rotation angle ϑ_{in}.

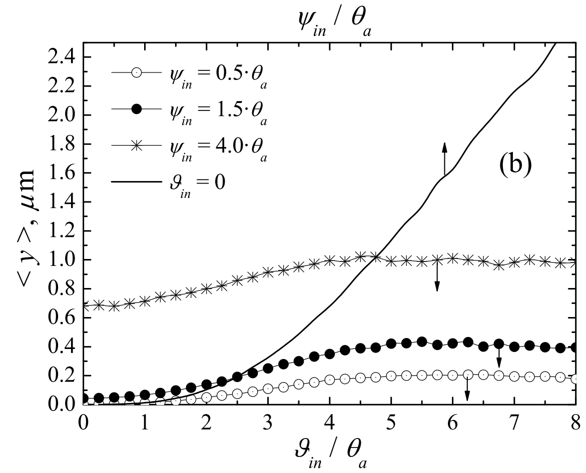

Fig.6. *Directional dependencies of mean depth $\langle y \rangle$ that coherently reflected electrons reach at the same modeling conditions that those of Fig. 2*

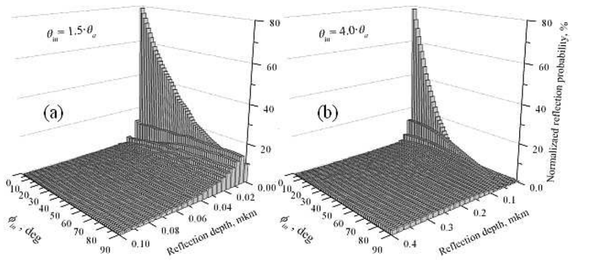

Fig.7. *The distributions $f_y(y)$ of coherently reflected electrons over the reflection depth y as functions of transversal azimuthal angle ϕ_{in} at different constant transversal energies*

Therefore the coherent reflection displays the same trend in the directional dependencies of angular distributions that are peculiar for the conventional three-dimensional incoherent backscattering from amorphous media. But here they are manifested only in the transversal 2D space of surface channel. The above-mentioned transition evidently follows from the data of Fig.9 shown for fixed initial transversal energies. On can see that at oblique initial azimuthal angles $\phi_{in} < 20°$ the peaks at definite emergency angles ϕ_{out} appear that are close to the directions of specular reflection in the transversal plane: $\phi_{out} \approx 180° - \phi_{in}$.

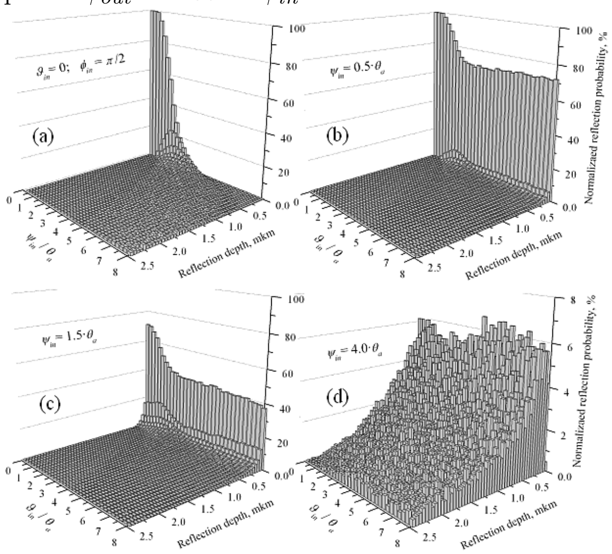

Fig.8. *The distributions $f_y(y)$ of coherently reflected electrons over the reflection depth y at normal transversal incidence (a)and as functions of crystal rotation angle ϑ_{in} at different fixed grazing angles ψ_{in} (b-–d)*

The comparison of angular distributions of Fig.9,a,b for different total incident angles θ_{in} shows that the effect is more pronounced at large transversal energies. But in all cases the azimuthal angular distribution of grazing transversal reflection is broad enough to state that it is originated from multiple collisions of electrons with atomic strings. At normal transversal incidence (see Fig.10,a) azimuthal angular distributions have broad maxima at the emergency azimuth $\phi_{out} = 90°$ i.e. at normal direction of transversal momentum. The distributions become slightly narrower as the incident grazing angle ψ_{in} increases when the particle reflection at grazing azimuthal angles $\phi_{out} \rightarrow (0°, 180°)$ is blocked more effectively.

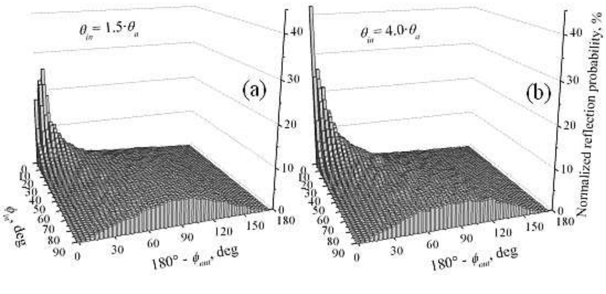

Fig.9. *Azimuthal angular distributions of coherently reflected electrons in the transversal plane as functions of the transversal incidence angle ϕ_{in} at fixed transversal energies*

The transition from normal to oblique transversal incidence with simultaneous growth of transversal energy is realized with the increase of the rotation angle ϑ_{in}. This is demonstrated by distributions shown in Fig.10,b–d.

The asymmetry is the most acute at small ψ_{in} because at such grazing angles in accordance with the curves of Fig.1,b the angle ϕ_{in} decreases with the increase of ϑ_{in} more rapidly. It is a kind of pure geometric effect. As ψ_{in} increases certain broadening of azimuthal distributions takes place (see Fig.10,c,d).

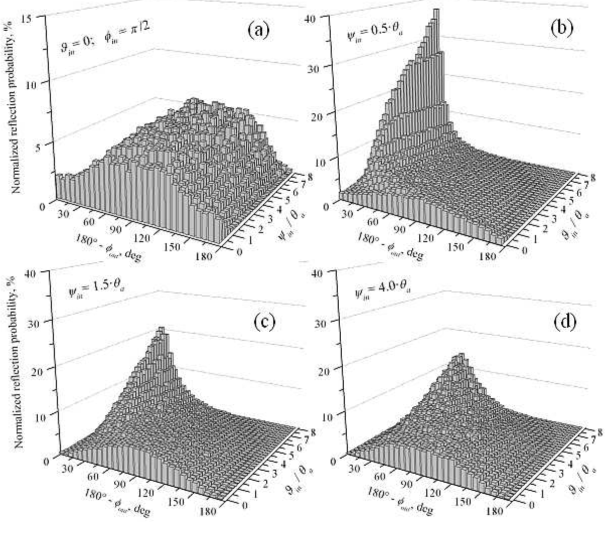

Fig.10. *Azimuthal angular distributions of coherently reflected electrons at normal transversal incidence (a) and as functions of angle ϑ_{in} of beam orientation with respect to axial surface channel direction at fixed grazing angles ψ_{in} (b-–d)*

Angular distributions of coherently reflected electrons over angles ψ_{out} with respect to surface plane are shown in Fig.11. Due to the conservation of transversal energy at pure coherent scattering the total emergency angle $\theta_{out} = \theta_{in}$ and according to Eq. (1) the reflection of electrons at angles $\psi_{out} > \theta_{in}$ is impossible. This is evidently remarkable in Fig.11.

Also one can see that at normal transversal incidence ($\vartheta_{in} = 0°$, see Fig.11,a) sharp maxima of distributions are located near the incidence angle ψ_{in}; thus in this case the coherent reflection is close to the specular one. The width of distribution curves grows with the increase of ψ_{in}.

The angular distributions directional dependencies on the rotation angle ϑ_{in} (see Fig.11,b-d) can be qualitatively interpreted within the scope of certain asymptotically bi-fractional model.

From the one hand the quasi-specularly reflected electrons at emergency angles $\psi_{out} \approx \psi_{in}$ are observed. In view of the conservation of $E_{\perp}$ for these electrons the correlation $|\vartheta_{out}| \sim |\vartheta_{in}|$ has to be satisfied. This implies that $\pi - \phi_{out} \sim \phi_{in}$ for this fraction of reflected beam. Thus the peak of specular reflection is formed by electrons that have experienced quasi-specular reflection in the transversal plane. Their contribution is more expressed at small ψ_{in} (see Fig.11,b) and blurs as ψ_{in} increases.

Another fraction of electrons emerges at grazing angles ψ_{out} that are close to θ_{in}, the total angle with respect to axis. The equation (1) implies that $\vartheta_{out} \rightarrow 0$ and therefore $\phi_{out} \rightarrow 90°$ for this fraction. The transversal projections of such electrons' momenta are close to the surface normal. This fraction of the coherently reflected beam is due to electrons that have experienced strong multiple transversal scattering by atomic strings and practically have lost information on the initial incident azimuth.

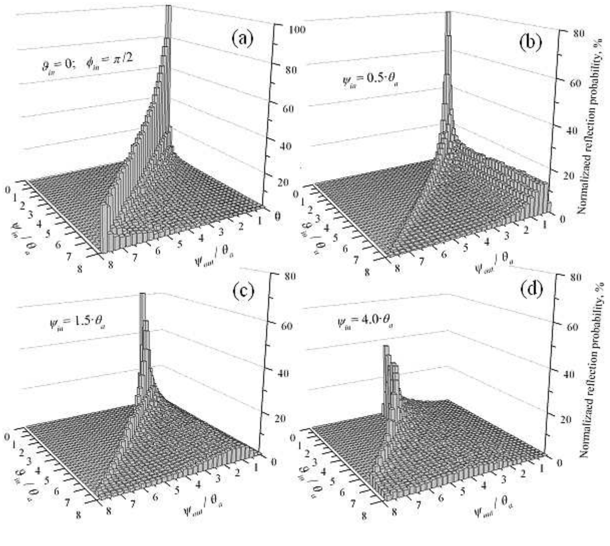

Fig.11. *Angular distributions of coherently reflected electrons over the grazing emergency angle ψ_{out} at normal transversal incidence (a) and as functions of angle ϑ_{in} of beam orientation with respect to axial surface channel direction at fixed ψ_{in} (b—d)*

The behavior of these fractions follows from the dependencies of angular distributions over ψ_{out} on ϕ_{in} shown in Fig. 12. In the broad range of azimuthal angles ϕ_{in} near the surface normal the reflection at angles $\psi_{out} \rightarrow \theta_{in}$ dominates that is due to the multiple axial scattering. It spreads toward smaller ψ_{out} when the transversal incidence becomes oblique. At grazing one ($\phi_{in} < 20°$) the expressed peak appears at small ψ_{out}. It describes the coherent reflection at the specular angle $\psi_{out} \approx \psi_{in} = \theta_{in} \cdot \sin \phi_{in}$ with respect to the crystal surface.

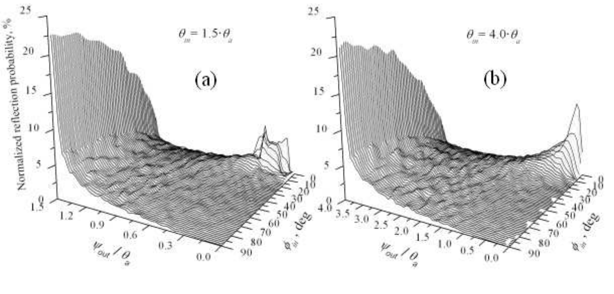

Fig.12. *Angular distributions of coherently reflected electrons over grazing emergency angles ψ_{out} as functions of the transversal incidence angle ϕ_{in} at fixed transversal energies*

Indeed quantitatively the partitioning of reflected beam onto these two fractions looks somewhat voluntary because in fact there exist noticeable amount of reflected electrons that occupy intermediate positions between these two limiting cases of coherent reflection.

4. DISCUSSION AND CONCLUSIONS

As a result of computer experiments the comprehensive description of directional effects in the classical coherent reflection of electrons at axial surface channeling has been obtained for the first time. It has been shown that this mechanism of particle reflection from crystalline surfaces differs qualitatively from the conventional backscattering from disordered media being dependent not only on the beam grazing incidence angle but on the supplementary directional parameter, the angle with respect to surface low-index atomic chains.

As it is evident from angular distributions, it demonstrates either the effect of pure axial scattering ("string effect") or the effect determined from the surface planarity ("plane effect"). These are the major qualitative directional effects that are supposed to be observed in the glancing backscattering experiments at high energies.

The former one is tracked in the existence of particles reflected at grazing angles close to the beam incident angle to atomic chains at any angles of glancing incidence. The latter one is responsible for the quasi-specular reflection at grazing angles close to the incident grazing angle itself. It dominates for large beam misalignments with respect to chains and corresponds to the glancing incidence in the transversal plane. Thus even for negatively charged electrons the crystal surface can effectively behave as a specularly reflected plane though (opposite to the case of planar coherent reflection of ions and positrons) this fact is due to the transversal scattering in a thick enough near-surface layer of crystal.

The modeling results have confirmed high efficiency of coherent reflection mechanism in a broad angular range of incidence as compared with the Lindhard angle. They indicate that coherent reflection is determined by the complex kinetics of transversal multiple scattering of electrons and therefore constitutes the physical effect that has to be described within the generalization of the known theory of directional effects in multiple scattering [7, 8] to the case of semi-infinite media.

Finally one should notice that such a theory as well as further computer simulation efforts have to take into account certain important effects that are currently omitted in our model not assigned to reproduce all actual experimental conditions. It concerns the incoherent multiple and single nuclear scattering that leads to the non-conservation of transversal energy and gives rise to the incoherently reflected fraction of electrons [3]. The total energy losses of particles shall be included that can be significant because certain fraction of reflected electrons travel in crystal by macroscopic distances. Also it is expected that supplementary directional effects in angular distributions of reflected electrons can arise from the ordered structure of atomic chains lattice [4] as well as from the morphology of real surfaces.

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ОРИЕНТАЦИОННЫЕ ЭФФЕКТЫ В АЛЬБЕДО И УГЛОВЫХ РАСПРЕДЕЛЕНИЯХ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОНОВ, ОТРАЖЕННЫХ ОТ МОНОКРИСТАЛЛОВ ПРИ СКОЛЬЗЯЩЕМ ПАДЕНИИ

С.В. Дюльдя

Методами компьютерного эксперимента исследованы ориентационные эффекты в когерентном отражении релятивистских электронов от поверхности кристаллов при скользящем падении в условиях аксиального поверхностного каналирования, когда отражение определяется азимутальным многократным рассеянием частиц на атомных цепочках. Рассчитаны ориентационные зависимости коэффициентов отражения, длин пробега, глубин проникновения в кристалл и угловых распределений обратно рассеянных частиц. Их анализ позволил выявить ориентационные эффекты цепочек, проявляющиеся в отражении под углами скольжения, близкими к углу ориентации оси пучка к направлению атомной цепочки, и кинетически обусловленные эффекты плоскости, приводящие к зеркальному отражению и доминирующие при больших азимутальных разориентациях пучка к низкоиндексным кристаллографическим направлениям.

ОРІЄНТАЦІЙНІ ЕФЕКТИ В АЛЬБЕДО ТА КУТОВИХ РОЗПОДІЛАХ РЕЛЯТИВІСТСЬКИХ ЕЛЕКТРОНІВ, ВІДБИТИХ ВІД МОНОКРИСТАЛІВ ЗА УМОВ КОВЗНОГО ПАДІННЯ

С.В. Дюльдя

Методами комп'ютерного експерименту досліджені орієнтаційні ефекти у когерентному відбитті релятивістських електронів від поверхні кристалів за умов ковзного падіння та аксіального поверхневого каналювання, коли відбиття визначається азимутальним багаторазовим розсіюванням частинок на атомних ланцюжках. Розраховані орієнтаційні залежності коефіцієнтів відбиття, довжин пробігу, глибин проникнення у кристал та кутових розподілів зворотно розсіяних частинок. Їх аналіз дозволив виявити орієнтаційні ефекти ланцюжків, що ведуть до відбиття під ковзними кутами, близькими до кута орієнтації вісі пучка до напрямку атомного ланцюжка, та кінетично обумовлені ефекти площини, що призводять до дзеркального відбиття та домінують за великих азимутальних разорієнтацій пучка до низькоіндексних кристалографічних напрямків.