FEATURES OF THE INTERACTION OF RELATIVISTIC ELECTRONS WITH AMORPHOUS AND SINGLE-CRYSTAL SUBSTANCES

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The experimental data analysis of the secondary electron emission yield during the interaction of amorphous and single-crystal structures with high-energy electron beams is presented. The universal dependence of the delta electron yield for thin targets with Be -74 µm, Ni - 10 µm, Cu - 150 µm, and Nb 20 is supplemented with experimental data measured in 2024. Taking into account the accumulated experimental data, the dependence of the secondary low-energy electrons yield with an energy of up to 50 eV on the energy of primary electrons in the region from 0.5 to 1200 MeV is shown. The issues of the distribution of secondary electrons versus primary energy electrons are discussed.

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INTRODUCTION

At the NSC "KIPT" of the NAS of Ukraine, experimental and theoretical studies of the interaction of electrons and positrons with matter began in 1970. The decisive factor in developing this work was developing low-divergence, monochromatic, and intense beams of electrons and positrons at linear accelerators at 300 MeV and 2 GeV[1].

One of the important aspects that attract the attention of theory and experiment to the process of interaction of electrons and positrons with single crystals is the possibility of generating gamma-quantum beams with a significantly higher spectral-angular density compared to the traditional method of bremsstrahlung of charged particles in an amorphous target. This feature of the interaction of charged particles with crystals has been discussed in a large number of original papers and several reviews. Much experimental research carried out in this direction is devoted to the study of various aspects of the physics of the process of interaction of charged particles with single crystals with different atomic numbers (C, Si, Ge, Nb, W), crystal thickness and orientation of crystallographic axes and planes relative to the direction of the primary beam of charged particles[2-9].

As a result of experimental and theoretical studies, the understanding of the mechanism of interaction of charged particles with single crystals and amorphous substances has been significantly expanded. However, from the point of view of practical applications, several areas remain insufficiently studied.

One of these areas is the study of the emission properties of amorphous and monocrystalline substances during the passage of relativistic electrons and positrons.

The study of secondary emission when excited by high-energy electrons when passing through thin films on a beam allows to obtain experimental data that significantly expand the understanding of the interaction of radiation with matter (amorphous and single-crystal) as a set of factors that lead to a change in the parameters of the internal state of experimental samples. This approach differs significantly from the approach that, for example, is implemented in software products for modeling the interaction of radiation with matter. It is the effects associated with the release of secondary emission that makes it possible to estimate the change in the energy distribution of free electrons in matter, namely the plasma of a solid.

In contrast to the method of measuring secondary emission under low-energy excitation, a comprehensive technique of studying the cross-beam of thin films has been proposed and developed at the NSC KIPT, which allows obtaining emission data from the front and back surfaces along the movement of the primary beam, evaluating the spectral characteristics of both outputs, comparing their contributions, investigating the yield of secondary high-energy electrons (delta electrons), and determining effects related not only to the properties of the material and its surface but also to the influence of the energy of the primary beam on secondary emission [10-12].

UNIVERSAL DEPENDENCE OF DELTA ELECTRON YIELD

When studying the interaction of electron beams with amorphous and single-crystal targets, there is a need to obtain universal dependencies that would allow estimating and predicting the delta-electron yield regardless of the primary beam energy, target thickness, or Z. Generalizing data on the delta-electron yield depending on the primary electron beam energy, target thickness, and chemical element based on the available experimental data on the delta-electron yield makes it possible to estimate the value of the average cross-section for the formation and yield of delta-electrons from thin targets [13]. The paper additionally presents experimental results (Fig. 1.) on the delta-electron yield obtained at the LPE-30 electron accelerator of the NSC

KIPT at an energy of 25 MeV for foil targets: Be - 74 μm, Ni - 10 μm, Cu - 150 μm, and Nb 20 μm in 2024.

The delta-electron yield is proportional to the value of ($T^{0.5}$·Z/A) and does not depend on the initial electron energy. Thus, the main factor in the increase in the delta-electron yield is not the energy of the primary beam but the electron density in the target. It has been confirmed that the delta-electron yield is proportional to the product ($T^{0.5}$·Z/A), where T is the sample thickness in g/cm^2 , and has a linear dependence [14].

The results obtained from the delta-electron yield make it possible to estimate the thickness of free foils and, in some cases to determine their chemical composition, where elements with not close Z are present, the orientation of single-crystal structures and the ratio of the crystalline phase to the amorphous phase.

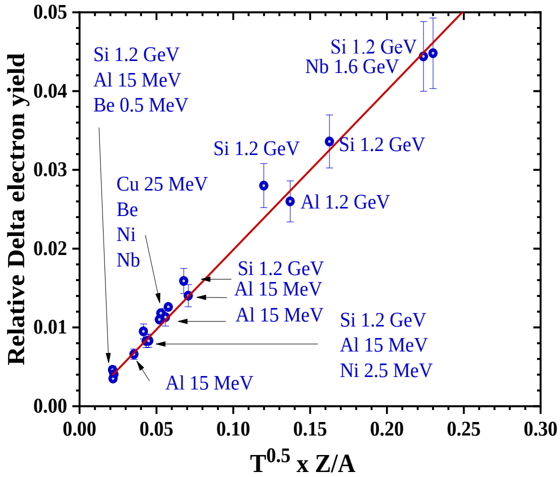

Fig. 1. Dependence of delta-electron yield

LOW ENERGY ELECTRON YIELD

Dependence of the yield of low-energy electrons on the Z target. In Fig. 2 shown the experimental results of the total yield of low-energy electrons for primary electron energy beam of 25 MeV for Be (74 μm), Al (50 μm), Ni (10 μm), Cu (15 μm) and Nb (20 μm).

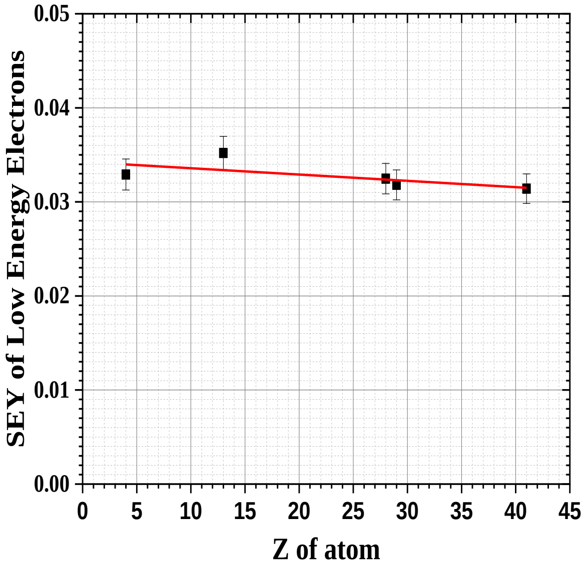

Fig. 2. Dependence of the yield of low-energy electrons versus the Z target

Taking into account experimental errors, it can be concluded that there is no dependence of the yield of low-energy electrons (up to 50 eV) on Z.

Dependence of the low-energy electron yield versus energy of the primary electrons.

Experimental data of low energy secondary electron yield is presented in Table. The energy range of primary electrons is from 2.5 to 1600 MeV. In the Table 1 C1 – emission yield from front surface of experimental target, C2 – from back side and C1+C2 – sum of the low energy secondary electron yield without **δ-**electron emission respectively. Si-p, Nb-p [14, 15] means that the crystals are disoriented relative to the electron beam, Si-o, Nb-o - the crystals are oriented relative to the direction of the electron beam. In Fig. 3 the linear approximation was used for fitting the dependence of low-energy electron yield versus primary electron energy is presented for back forward and sum emission.

Dependence of the yield of low-energy electrons versus primary electron energy

Target	E, MeV	C1-δ	C2-δ	C1+C2-δ
Al	2.5	1.18	0.96	2.3
Al	10	1.6225	1.5075	3.15
Al	15	1.56	1.33	2.89
Al	20	1.66	1.47	3.10
Al	25	1.87	1.63	3.52
Al	30	1.655	1.46	3.1
Si-p	1200	2.61	1.6	4.33
Si-o	1200	2.83	1.65	4.5
Nb-p	1600	2.96	1.84	4.8
Nb-o	1600	3.09	1.94	4.89

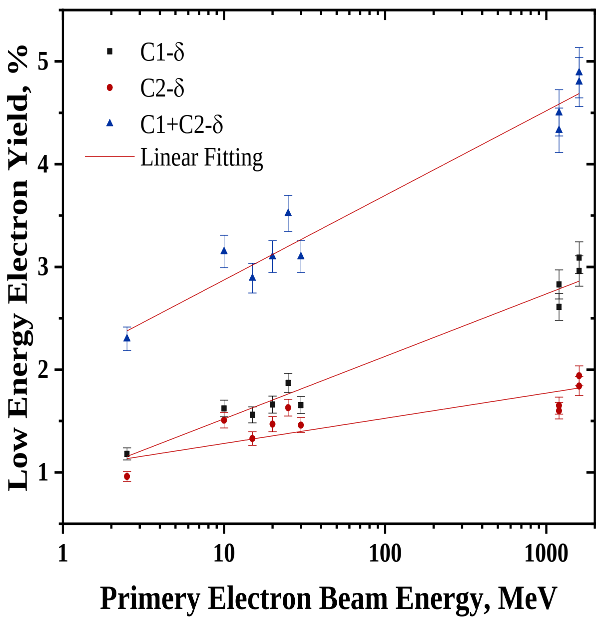

Fig. 3. Dependence of the yield of low-energy electrons on energy

As expected, a significant dependence of electron emission on their initial energy is observed. To a lesser extent, this dependence is observed for emission from the second surface. For an initial electron energy of

2.5 MeV, the emission from the first and second surfaces is practically equal. With an increase in the energy of the initial electrons, the emission values increase, but their values for Si [15] and Nb [16] are practically equal (i.e., they do not depend on Z).

SPECTRA OF ELECTRONS LEAVING THE TARGET

The yields of the low-energy component of secondary emission and the spectra of the outgoing electrons are measured experimentally, which cannot coincide with the spectra of ionized electrons in the metal, since high-energy electrons can emerge from a greater depth of the metal, the proportion of their yield is greater, which leads to deformation of the original spectrum of electrons of ionization [17].

The initial spectrum of ionized electrons of exponential type at the exit is transformed into a spectrum with a characteristic maximum. This is confirmed both by Monte Carlo modeling of secondary emission [18] and by measurements [19].

The yields of secondary electron emission at the LUE-30 electron accelerator were measured at a primary electron energy of 25 MeV.

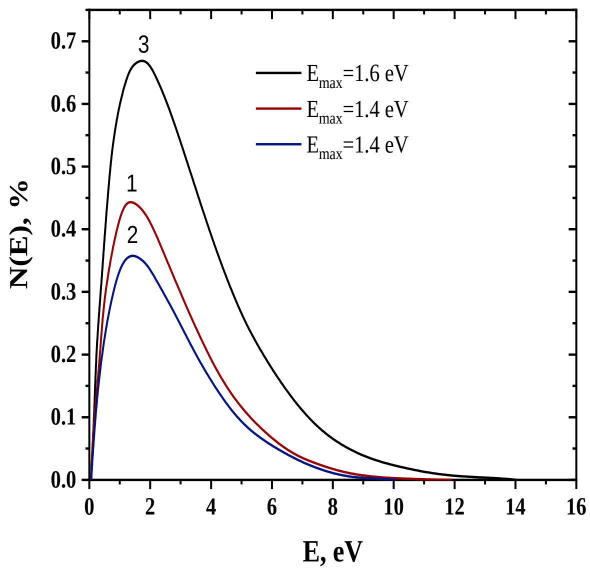

Fig. 4. The spectrum of electrons emerging from the target, normalized to the incident electron flux with an energy of 25 MeV. Curve 1 is the spectrum of electrons emerging from the first surface, curve 2 is the spectrum of electrons emerging from the second surface, and curve 3 is the total spectrum from the two surfaces

The maximum of the spectrum of electrons emerging from the 1st surface is at an energy of 1.4 eV, from the 2nd – at 1.4 eV, and the maximum of the total yield is at 1.6 eV. At an initial primary beam energy of 25 MeV, the value of the spectrum of the yield from the 1st surface slightly exceeds the value of the yield from the second surface, and the integrals over the spectra are equal to the values of the total secondary emission yield for each measurement.

CONCLUSIONS

The yield of delta electrons is proportional to the value of $T^{0.5}$·Z/A and does not depend on the initial energy of the electron (for which the decrease in the initial energy of the electrons can be neglected). The yield of low-energy electrons depends on the initial energy, as *Ln(E)*. With an increase in the initial energy of the electron, the difference between the emission with the first and second surfaces increases. The emission of low-energy electrons does not depend on the Z of the target. The maximum of the spectrum of the outgoing surface electrons is in the energy range of 1.4…1.6 eV.

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