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Secondary Electron Emission Induced by Channeled Relativistic Electrons in Si Crystal

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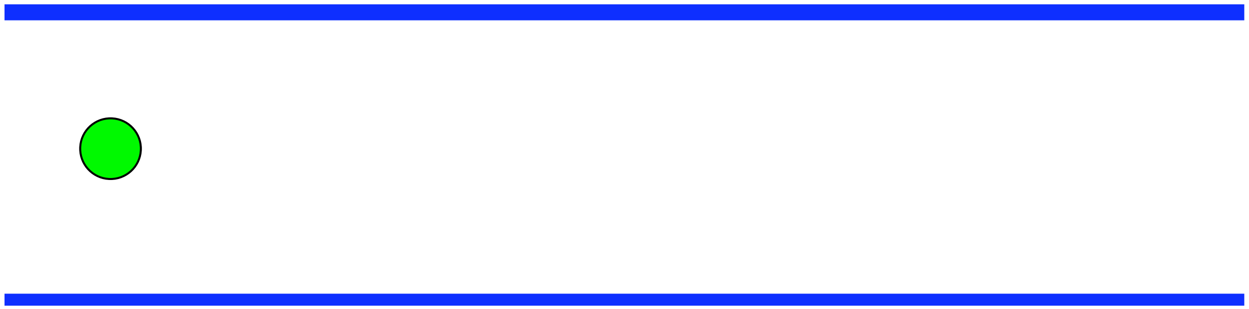
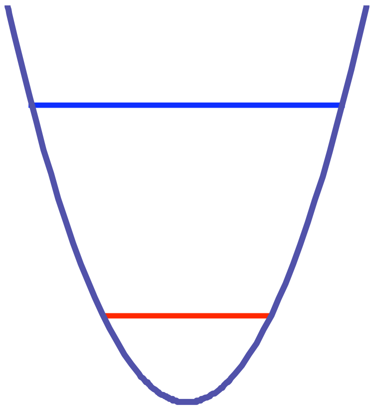
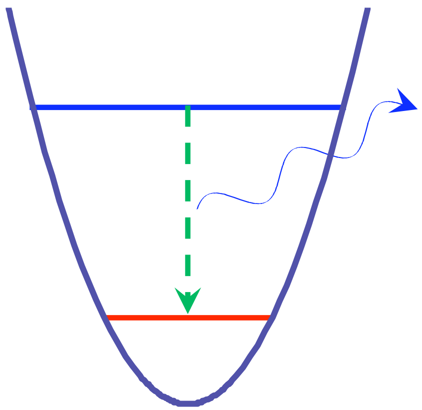
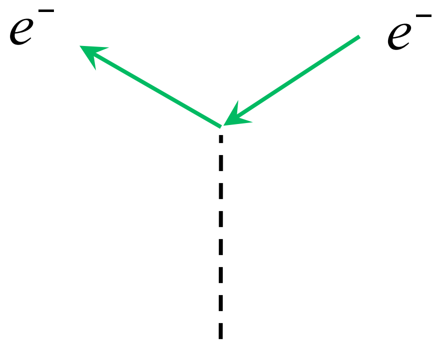
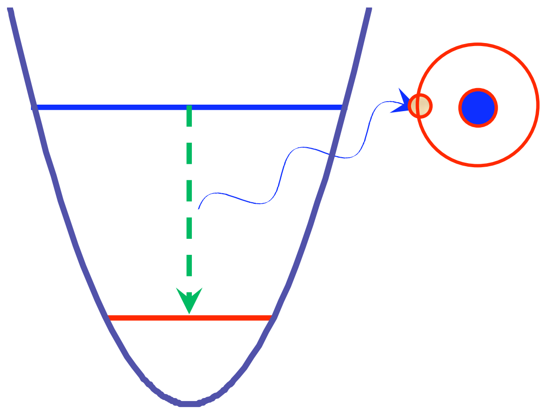


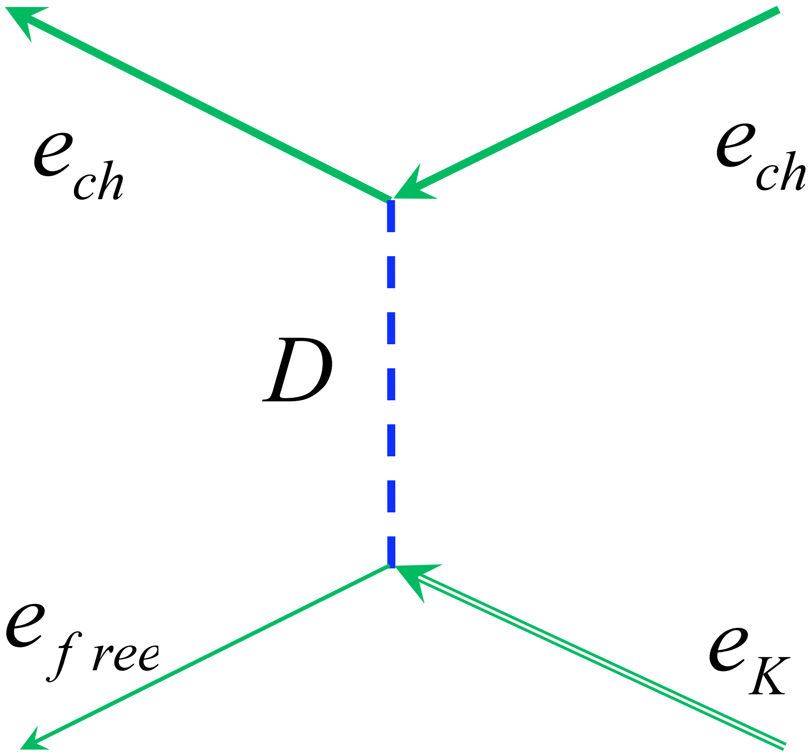


Кumaкhov M.A. // Phys. Lett. Ser. A, 1976, v. 57, p. 17; Dokl. Akad. Nauk USSR, 1976, т. 30, с. 1077 (in Russian).
Baier V. N., Katkov V. M., Strakhovenko V. M. Electromagnetic Processes at High Energies in Oriented Single Crystals, World Scientific Publishing Co, Singapore, 1998.
Bazulev V.A. Zhevago N.K. Radiation of Fast Particles in Matter and External Fields Moscow., Nauka.,1987 (in Russian).









Secondary Electron Emission
Induced by Channeled Electrons

Nitta H., Ohtsuki Y. H. // Phys. Rev. B. 39 (1989) 2051

$$d\sigma = \left|M_{if}\right|^2 \delta\left(\left(E_i + \varepsilon_{i\perp}\right) - \left(E_f + \varepsilon_{f\perp}\right) - E - E_K\right)\frac{1}{J}\,dv$$

$$M_{if} = e^2 \int d\vec{r}_1\, d\vec{r}_2\, \overline{\Psi}_f\left(\vec{r}_1\right)\gamma^j\, \Psi_i\left(\vec{r}_1\right) D_{jl}\left(\vec{r}_1, \vec{r}_2\right)\overline{\Psi}\left(\vec{r}_2\right)\gamma^l\, \Psi_K\left(\vec{r}_2\right)$$

$\Psi_i\left(\vec{r}_1\right)$ $\left(\Psi_f\left(\vec{r}_2\right)\right)$ **wave function of channeled electron**

$$\Psi\left(\vec{r}, t\right) = \Psi\left(\vec{r}\right)\exp\left(-iEt\right),$$

$$\Psi\left(\vec{r}\right) = \sqrt{\frac{m+E}{E}}\, u\phi\left(x\right)\exp\left(i\vec{p}_{\|}\vec{r}_{\|}\right), \quad u = \begin{pmatrix} w \\ \dfrac{\vec{\sigma}\cdot\hat{\vec{p}}}{m+E} \end{pmatrix}$$

Кumакhov M.A. // Phys. Lett. Ser. A, 1976, v. 57, p. 17;
Dokl. Akad. Nauk USSR, 1976, т. 30, с. 1077 (in Russian).

$$d\nu = \frac{d\vec{p}_{f\parallel}}{(2\pi)^2}\frac{d\vec{p}}{(2\pi)^3}$$ **the number of final states**

J **is the initial flux of the channeled electrons**

$$D_{jl}(\vec{r}_1,\vec{r}_2) = 4\pi\int \frac{1}{\omega^2 - k^2}\left(\delta_{jl} - \frac{k_l k_j}{\omega^2}\right)\exp\left[i\vec{k}(\vec{r}_2 - \vec{r}_1)\right]\frac{d\vec{k}}{(2\pi)^3}$$ **photon propagator**

nonrelativistic case:

$$\overline{\Psi}(\vec{r}_2)\gamma^l\,\Psi_K(\vec{r}_2) = \bar{u}\exp[i\vec{p}\cdot\vec{r}_2]\gamma_0\gamma^l u_K\Phi_K(\vec{r}_2)$$

$$= u^+\exp[i\vec{p}\cdot\vec{r}_2]\alpha^l u_K\Phi_K(\vec{r}_2) = u^+\exp[i\vec{p}\cdot\vec{r}_2]\,\hat{v}_i\,u_K\Phi_K(\vec{r}_2)$$

$$= \exp[i\vec{p}\cdot\vec{r}_2]\,\hat{v}_i\,\Phi_K(\vec{r}_2),$$

$\vec{\alpha} = \hat{\vec{v}} = \hat{\vec{p}}/m$ **operator of the velocity of electron**

$$d\sigma = \frac{4\pi^4}{\beta^2 m^2} e^2 \frac{(m+E_i)(m+E_f)}{\mathring{A}_f \mathring{A}_i} \left\{ (\vec{I}_1 + \vec{I}_1)(\vec{p} - \vec{\kappa}) - \frac{1}{\omega^2} ((\vec{I}_1 + \vec{I}_1)\vec{\kappa})((\vec{p} - \vec{\kappa})\vec{\kappa}) \right\}^2 J_K^2$$

$$\delta\left((E_i + \varepsilon_{i\perp}) - (E_f + \varepsilon_{f\perp}) - E - E_K\right) \frac{d\vec{p}_{f\|}\, d\vec{p}}{(2\pi)^5}$$

$$\vec{I}_1 = \left\{ \frac{1}{E_i + m} \int (\hat{p}_x \phi_f^*(x_1)) \phi_i(x_1) \exp[-i\beta x_1] dx_1 ,\ \frac{\vec{p}_{f\|}}{E_i + m} \int \phi_f^*(x_1) \phi_i(x_1) \exp[-i\beta x_1] dx_1 , \right\}$$

$$\vec{I}_2 = \left\{ \frac{1}{E_f + m} \int (\hat{p}_x \phi_i(x_1)) \phi_f^*(x_1) \exp[-i\beta x_1] dx_1 ,\ \frac{\vec{p}_{i\|}}{E_f + m} \int \phi_f^*(x_1) \phi_i(x_1) \exp[-i\beta x_1] dx_1 , \right\}$$

$$\vec{\kappa} = \{\beta, \Delta\vec{p}_{\|}\}\ \beta^2 = \omega^2 - \Delta p_{\|}{}^2,\ J_K = \int_0^\infty \frac{\sin((\vec{p} - \vec{\kappa}) r_2)}{|\vec{p} - \vec{\kappa}| r_2} \Phi_K(r_2) r_2{}^2 dr_2$$

Clementi E., Roetti C. // Atomic Data and Nuclear Data Tables, 1974, V. 14, P. 177.

$$\Psi(\boldsymbol{r},t)=\tilde{N}\exp\left(-iEt\right)\exp\left(i\vec{p}_{\|}\vec{r}_{\|}\right)\phi(x),\qquad E=\sqrt{(cp_{\|})^2+m_e^2c^4}$$

$$\frac{1}{2\gamma m_e}\frac{d^2\phi(x)}{dx^2}-V(x)\varphi(x)=\varepsilon_{\perp}\varphi(x)$$

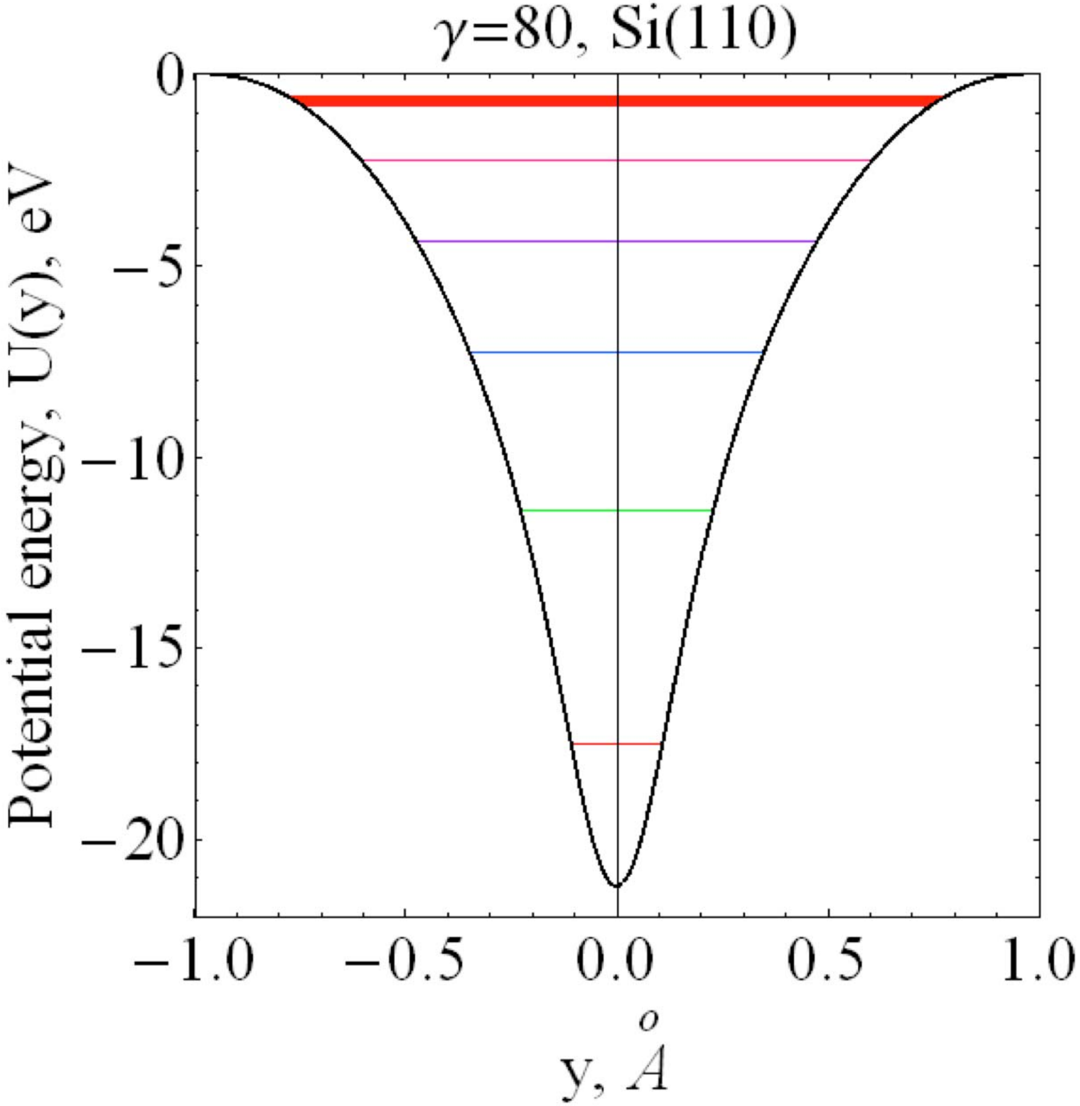
$$\phi^i(x,k_x)=\sum_m C^i(g_x,k_x)\exp\{i(k_x+mg_x)x\}$$

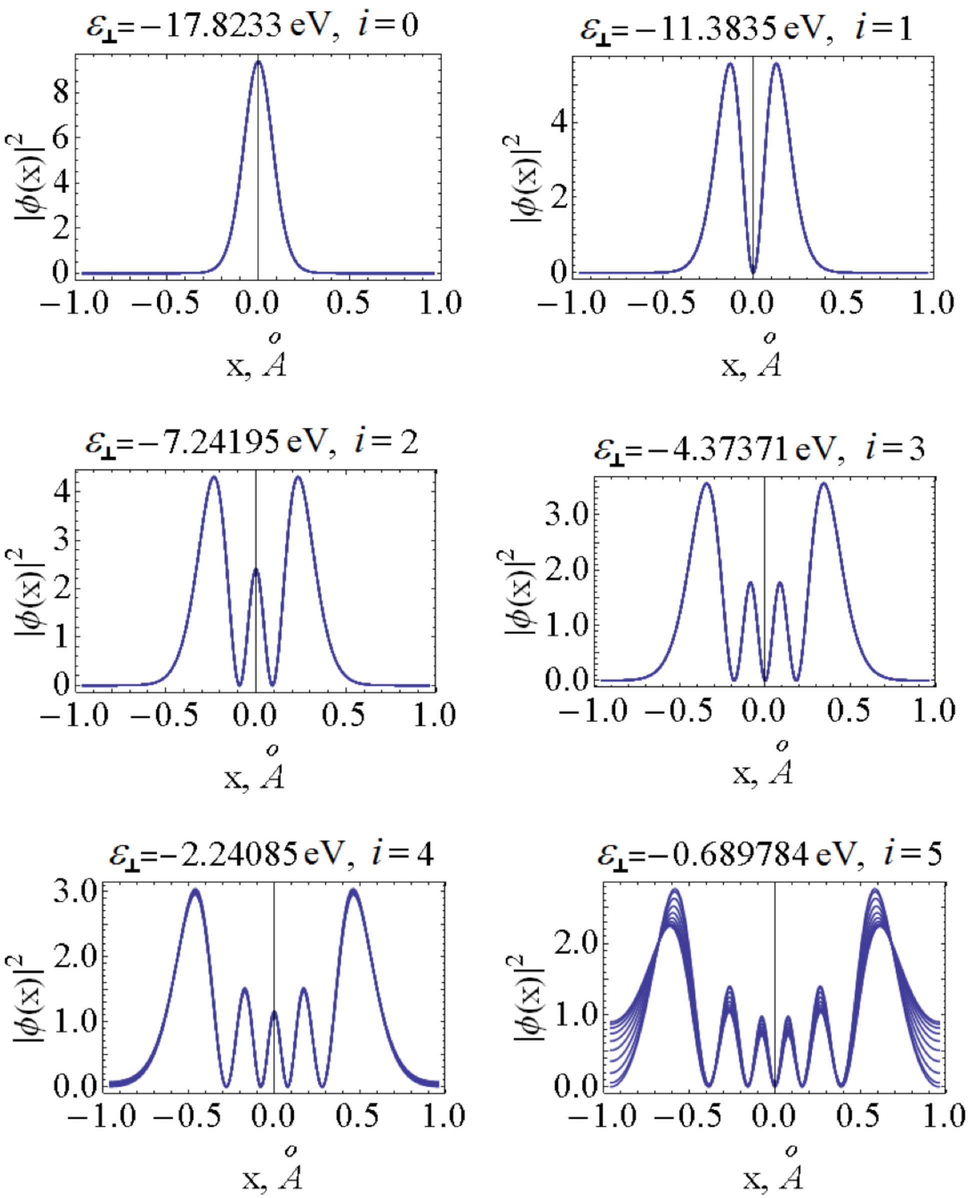
$C^i(g_{xm},k_x)$ **the expansion coefficients of the wave function in a Fourier series**

$$\sum_m A_{mn}C^i(g_{xm},k_x)=E^i(k_x)C^i(g_{xn},k_x),$$

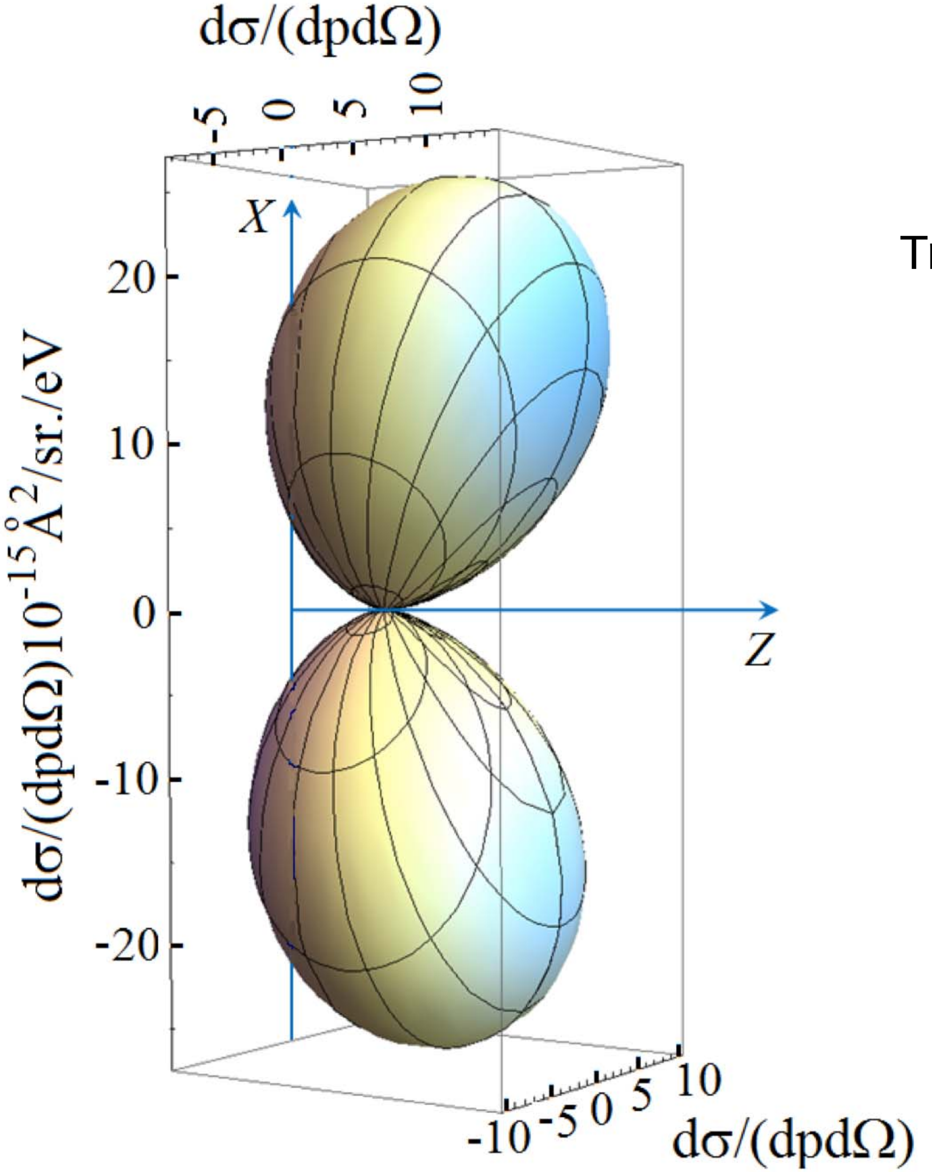
$$A_{mn}=U_{m-n}+\delta(m,n)(\hbar^2\left|mg_x+k_x\right|^2/2m_e\gamma).$$

U_m **the expansion coefficients of the potential function in a Fourier series**


γ=80, Si(110)
Potential energy, U(y), eV
0
−5
−10
−15
−20
−1.0
−0.5
0.0
0.5
1.0
y, Å



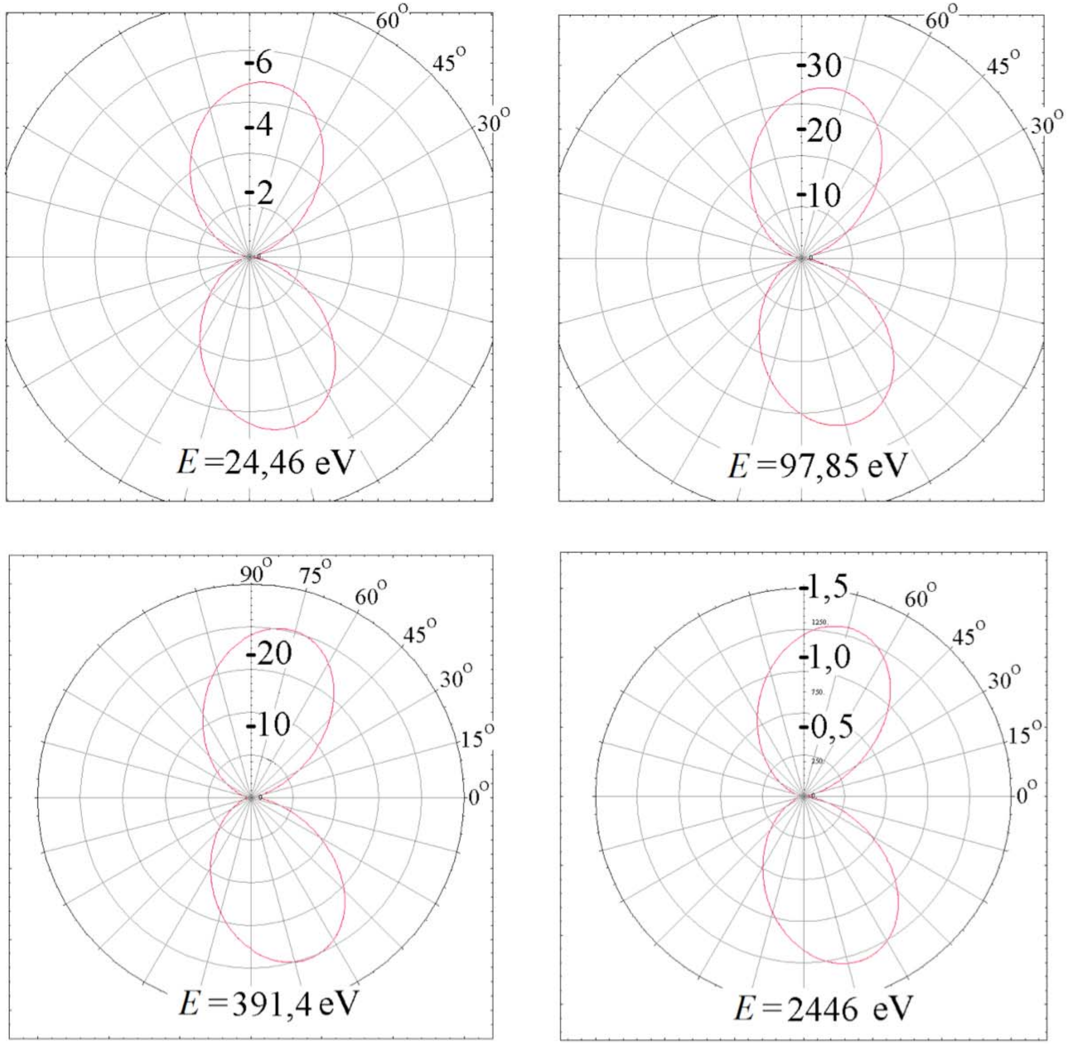
ε⊥=−17.8233 eV, i=0
ε⊥=−11.3835 eV, i=1
ε⊥=−7.24195 eV, i=2
ε⊥=−4.37371 eV, i=3
ε⊥=−2.24085 eV, i=4
ε⊥=−0.689784 eV, i=5
|φ(x)|²
x, Å



Transition
2→1

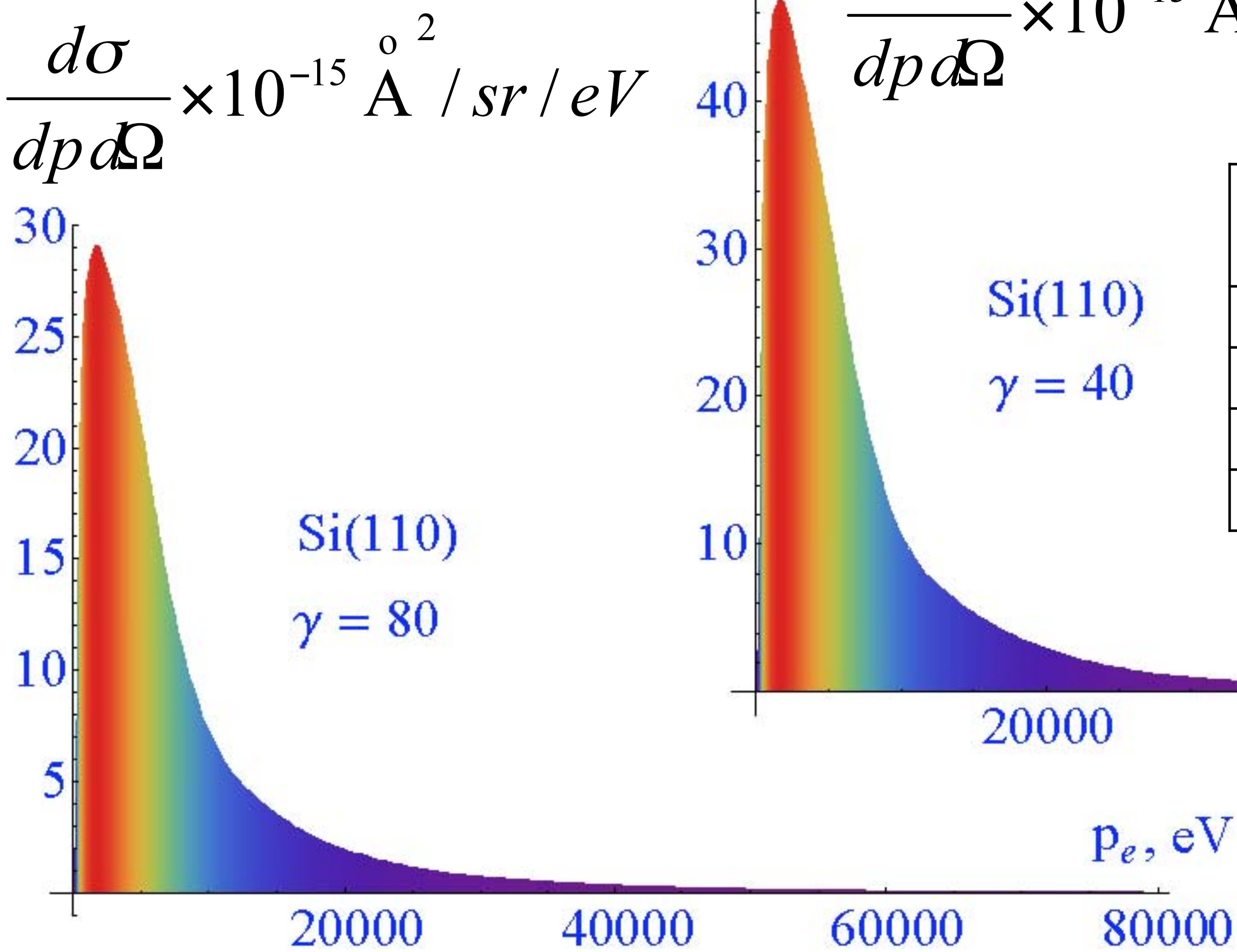
γ=80

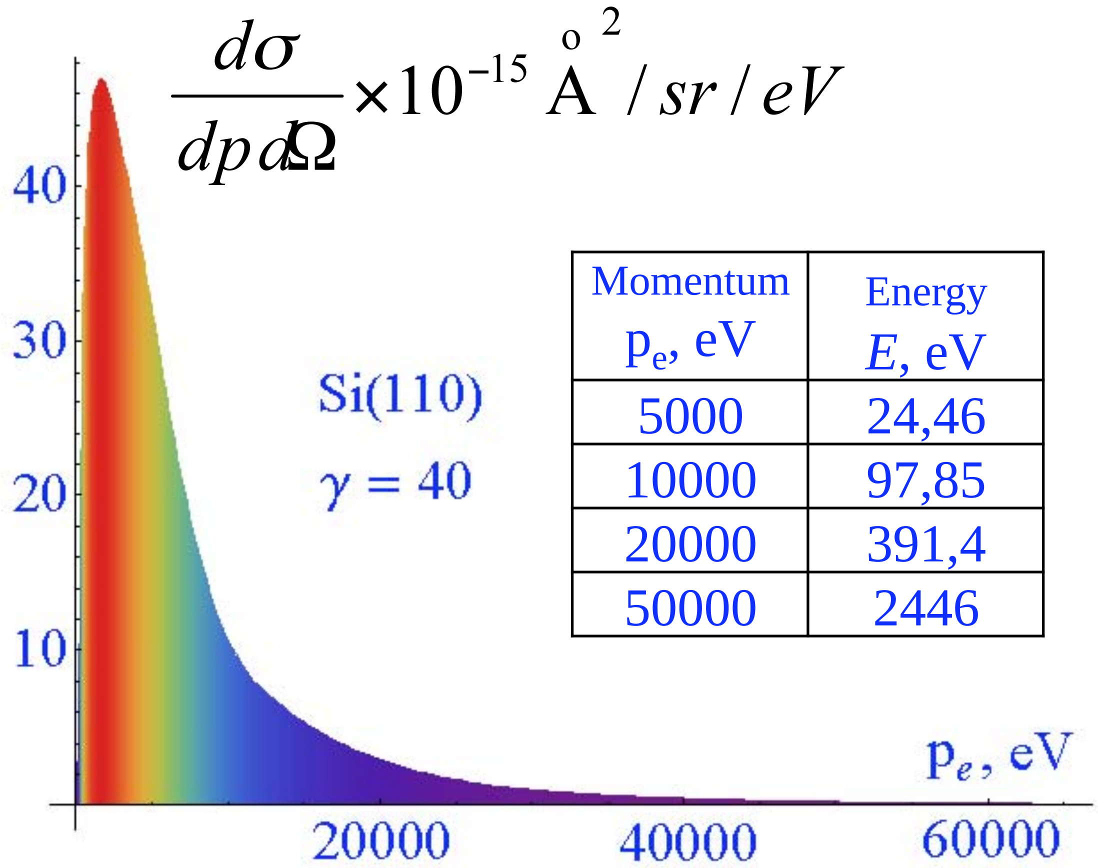
$d\sigma/(dp\,d\Omega)\ 10^{-15}\ \mathring{A}^2/\mathrm{sr./eV}$



$\gamma = 80$

Momentum p_e, eV	Energy E, eV
5000	24,46
10000	97,85
20000	391,4
50000	2446





Momentum p_e, eV	Energy E, eV
5000	24,46
10000	97,85
20000	391,4
50000	2446

	γ	$d\sigma/dpd\Omega\times10^{-5}$ barn/eV/sr	σ barn
Transition 2→1	16	1.49156	0.037
∑(3 bands)	16	511.563	12.6
∑(4 bands)	28	551.525	13.6
∑(5 bands)	44	1291.66	31.8
∑(6 bands)	70	1791.71	44.1
∑(8 bands)	100	4057.33	99.8

estimation

$\sigma_e \approx 1730$ barn

(according of formula Ref.[1])

$\gamma = 100$

1. *Schagin A.V., Sotnikov V.V.* // The Jornal of Kharkiv National University, No.777, physical series "Nuclei, Particles, Fields", Issue 2/34/, Kharkov, 2007, p. 97-101.

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Thanks for attention