13th International Workshop on the Physics of Non-Ideal Plasmas,
Chernogolovka, Moscow Region, 13-18 September 2009

Resonance penetration of intense femtosecond laser pulses through dense plasma of ultra-thin foils

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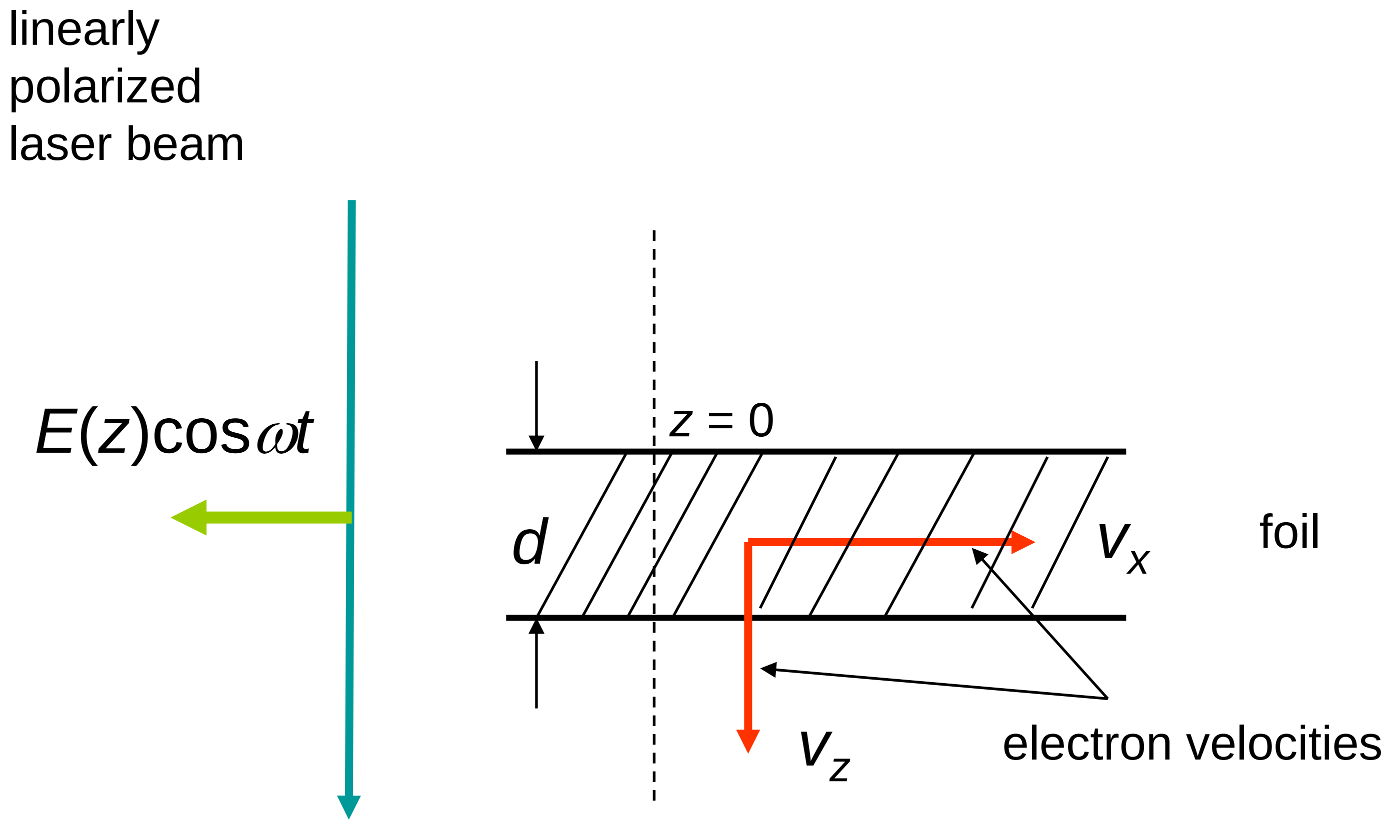
Published: JETP, **108**, 751 (2009)

Outlook

- Transmission coefficient for penetration of intense femtosecond laser pulse through dense plasma of an ultra-thin foil has been derived, as a function of foil thickness, *analytically* for the first time using the one-dimensional Vlasov-Boltzmann equation and taking into account absorption of radiation.
- Foil is destroyed only after termination of ultrashort femtosecond laser pulse.



We consider only bulk free electrons inside the foil and do not consider small part of strongly heated electrons

Maxwell-Vlasov-Boltzmann kinetic equations for the distribution function δf is of the form

$$i\omega\delta f - v_z \frac{d}{dz}\delta f = F(z)\frac{\partial f_0}{\partial v_x} - i\omega\frac{dF(z)}{dz}\left[v_x\frac{\partial f_0}{\partial v_z} - v_z\frac{\partial f_0}{\partial v_x}\right] - \frac{\delta f}{\tau}$$

$$\frac{d^2F(z)}{dz^2} = -\frac{4\pi i\omega}{c^2}\int v_x \delta f dv_x dv_z$$

τ is the time between collisions of an electron with an atomic ion inside the foil plasma resulting in induced inverse bremsstrahlung;

f_0 is unperturbed distribution function;

$F(z)$ is the field strength amplitude inside the foil;

plasma frequency ω_p >> laser frequency ω

Foil electrons are reflected elastically from both foil boundaries (as at the anomalous skin-effect)

We assume $$f_0\left(v_x, v_z\right) \square\, \delta\left(v_z^2 - v^2\right)$$

Integro-differential equation for the electric field strength in the absence of absorption:

$$\frac{d^2 E(z)}{dz^2} - \frac{\omega_L^2 \Delta}{c^2} E(z) = \frac{\omega}{c^2} \frac{\omega_L^2 (1-\Delta)}{v} \times$$

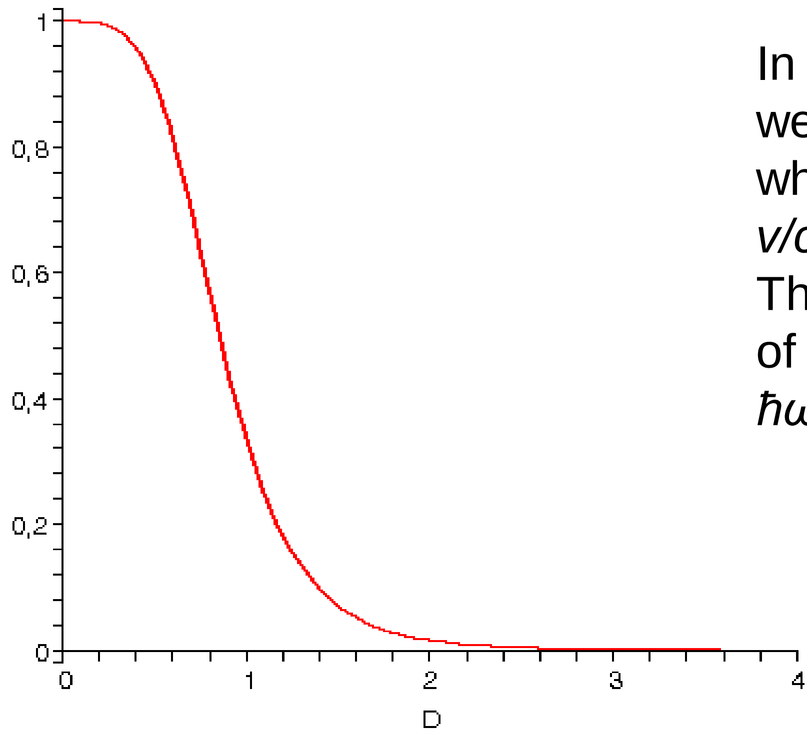
$$\times \left\{ \int_0^z dz' E(z') \sin\left[\frac{\omega}{v}\left(z - z'\right)\right] + \frac{\cos(\omega z / v)}{\sin\left(\omega d / v\right)} \int_0^d dz' E(z') \cos\left[\frac{\omega}{v}\left(d - z'\right)\right] \right\}.$$

$$\Delta = 1 - v_x^2 / v^2$$

It has been solved analytically!

Dependence of the transmission coefficient on the dimensionless foil thickness $D = d\omega / v$ when there is no transverse electron motion ($v_x = 0$)

Figure1

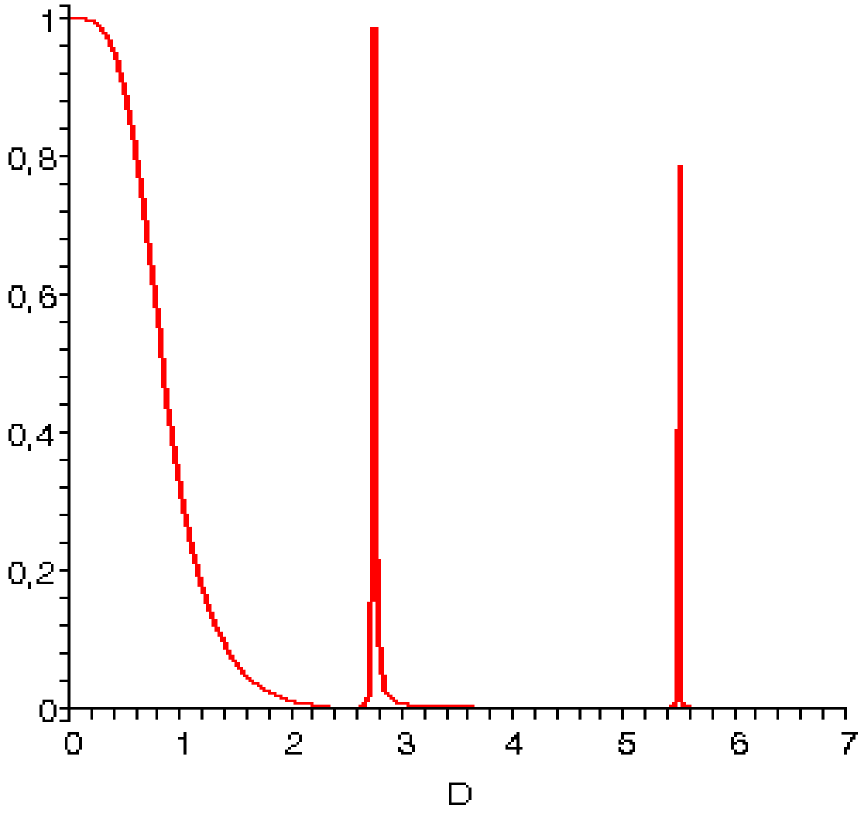


In the numerical example we consider the typical case when E_z = 1.5 keV, i.e. v/c = 0.08.
The photon energy of Ti:Sapphire laser is $\hbar\omega$ = 1.5 eV.

one obtains the well known damping of the electric field inside the foil on the skin depth of the order of 100 - 150 Å

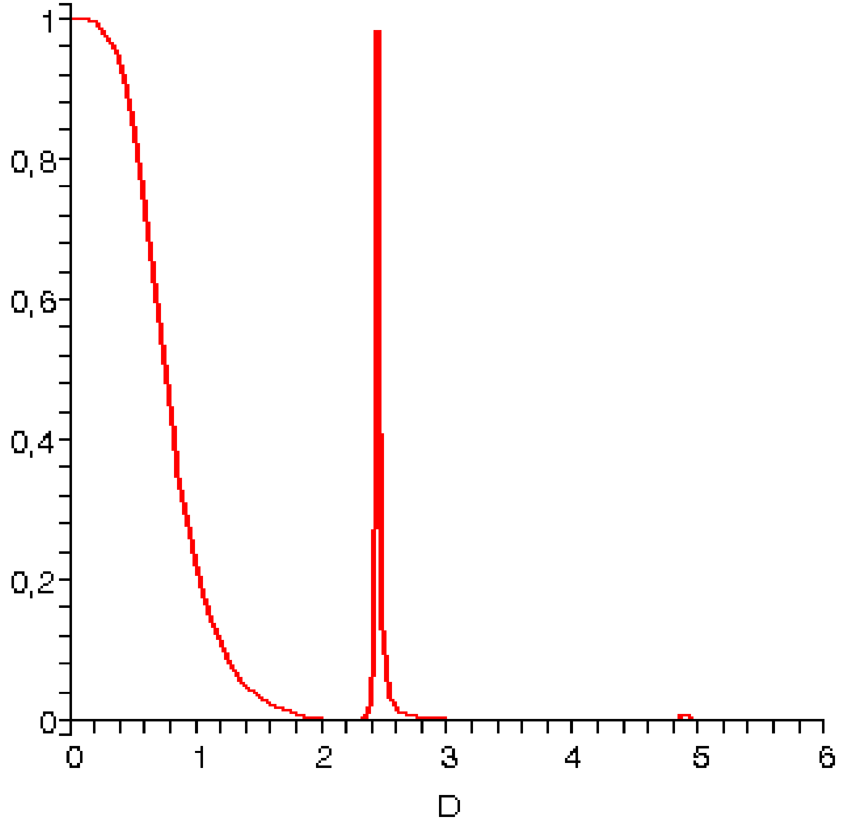
Resonance dependence of the transmission coefficient on the foil thickness $D = d\omega / v$ when transverse electron energy is equal to its longitudinal energy

Figure2

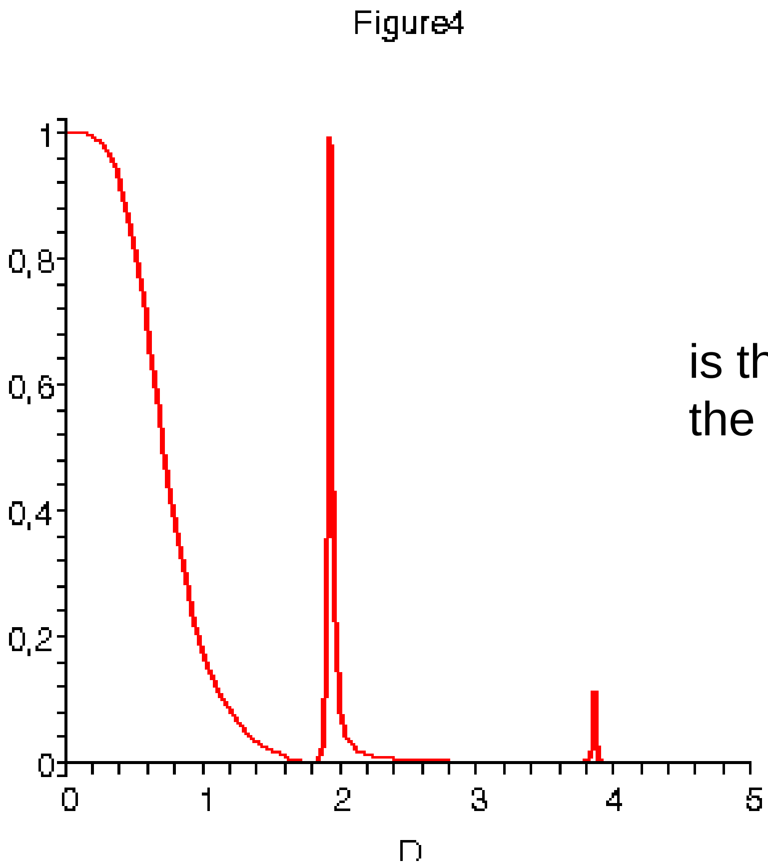


Resonance dependence of the transmission coefficient on the foil thickness *D* = *d*ω /*v* when transverse electron energy is equal to twice of its longitudinal energy

Figure3



Resonance dependence of the transmission coefficient on the foil thickness $D = d\omega /v$ when transverse electron energy E_x is equal to $6E_z$



$$\Delta d \approx \frac{\pi v}{\omega}$$

is the distance between the neighboring resonances

Conclusions

- We predict a non-monotonic behavior of the transmission coefficient with several peaks as a function of the ultra-thin foil thickness. Unlike results of Ref. (G. Ferrante, and S.A. Uryupin, Phys. Lett. A **345**, 205, 2005) , it can be observed also at isotropic velocity distribution of bulk electrons in foil plasma. The distance between resonances is of the order of

$$\pi v / \omega$$

Conclusions

- This effect can be used for measurements of the width of super-thin foils.
- For example, at the electron energy of 1.5 keV in all directions and Ti:Sapphire laser we obtain that this distance is of the order of 35 nm.