Scattering of ultrashort X-ray pulses in optically dense plasma: account for pulse duration and propagation effects

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Scattering of electromagnetic radiation in media is an important experimental tool to obtain information about the properties and state of matter. Recent advances in generating ultrashort laser pulses (USP) open perspectives of sub-femtosecond scattering processes. For ultra-short electromagnetic fields the scattering differs considerably from the standard long-pulse theory. One of the interesting properties is associated with the interaction of ultrashort pulses with dense matter: here, the short pulse propagation is characterized by possible resonance processes in the optically dense medium due to the large width of the frequency spectrum.

We consider a semi-analytical approach [1] that overcomes the failure of Fermi's Golden Rule in the description of the ultra-short photoprocess but maintains the possibility to employ cross sections (note, that the complex numerical solution of the time-dependent Schrodinger equation makes it difficult to employ measured cross sections). A central element of this approach is the probability induced by USP during all time of pulse action:

$$W(\tau)=\frac{c}{(2\pi)^2}\int_0^\infty \frac{\sigma(\omega)}{\hbar\omega}\left|E(\omega,\tau)\right|^2 d\omega. \quad (1)$$

$\sigma(\omega)$ is the cross section of the photoprocess and $E(\omega,\tau)$ is the Fourier transform of electric field strength in the pulse, τ is the pulse duration. This approach has been used [2] for the study of femtosecond X-ray pulse driven resonance scattering on ions in plasmas. It was shown particularly that the dependence of the scattering probability on the pulse duration can be nonlinear for certain values of pulse parameters even if the radiation intensity is small (1st order perturbation theory). The approach was generalized to account for the dependence on the pulse propagation length in optically dense hydrogen plasmas [3].

In the present work we account for the absorption of USP in optically dense hot plasmas employing the integral expression for the scattering probability:

$$W_{scat}(\tau,z)=\frac{c}{(2\pi)^2}\int_0^\infty \frac{\sigma_{scat}(\omega)}{\hbar\omega}\left|E(\omega,\tau)\right|^2 \exp\left[-N\sigma_{abs}(\omega)z\right]d\omega. \quad (2)$$

$\sigma_{scat}(\omega)$ and $\sigma_{abs}(\omega)$ are the scattering and absorption cross sections, respectively, *N* is the density of the scattering ions, z is the propagation length of the USP in the plasma. This expression allows to consider two new fundamental parameters in dense plasmas: (i) the ratio of the spectral resonance line width and the width corresponding to the pulse duration, (ii) the optical thickness of the medium.

Numerical calculations of the scattering probability (2) have been carried out for femtosecond USP resonance scattering on highly charged ions in hot dense plasmas with account for the fine structure splitting of the ionic energy levels and the Doppler effect. The dependencies of the scattering probability on pulse duration and propagation length were analyzed for different ionic charges at temperatures of about 100 eV and densities 10^{21}-10^{23} cm^{-3}. We also examine the influence of the pulse duration τ and plasma length z on the spectrum of the USP scattering probability for various ions. The analysis allows to explore the main features of USP scattering in dense hot plasmas.

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References

[1] V.A. Astapenko, Phys. Lett. A **374**, 1585-1590 (2010).

[2] F.B. Rosmej, V.A. Astapenko, V.S. Lisitsa, N.N. Moroz, Phys. Lett. A **381**, 3576-3579 (2017).

[3] A. Calisti, V.A. Astapenko, V.S. Lisitsa, Contr. Plasma Phys. **57**, 414-420 (2017).