Collisional heating and ionization of large metal clusters by intense femtosecond laser field

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Inverse bremsstrahlung heating is a well-known mechanism of intense laser pulse absorption by a matter, but up to now its role in interaction of femtosecond laser field with large clusters which radius exceeds skin depth remained unclarified. Some authors believe that as electron temperature approaches 0.5 – 1 keV collisional absorption becomes inefficient and typical T_e observed in kiloelectron volts domain cannot be attributed to it [1]. Another authors calculated $T_e > 150$ keV due to this mechanism at the irradiation of large Xe clusters (10^8 atoms) by laser pulse of $\tau = 100$ fs duration and intensity 10^{18} W/cm^2 [2]. Spatial field structure and absorption cross-section analysis permits us to point out region of laser pulse and large metal clusters parameters at which effective inverse bremsstrahlung heating and impact ionization occur [3]. Simple analytical expressions for field structure inside and outside of a dense uniform cluster, absorption and scattering cross sections are derived in two limiting cases when skin depth δ is considerably greater or smaller than cluster radius R. It is shown that usually used quasi-static expression for electric field inside a cluster [4] and corresponding absorption cross-section Q_0 are valid only in the zero order approximation on parameter $\rho = 2\pi R/\lambda$ under condition of $\delta >> R$. Even if $\delta >> R$ substantial contribution to the cluster heating can be made by induction electric field in the first order on ρ if module of dielectric permittivity $|\varepsilon|$ becomes sufficiently large as in the case of metal clusters. Using Q_0 in case of $\delta << R$ if $|\varepsilon|$ increases owing to ionization leads to strong underestimation of absorption cross-section Q_a. On other hand, statement that absorption cross-section coincides with cluster geometrical cross-section when $\delta < R$ [2] can result in a strong overestimation of Q_a.

Simulations are undertaken with parameters of IHED femtosecond IR laser complex. It is determined that optimal for heating iron cluster radius equals 20 – 25 nm. Electron temperature substantially depends on laser intensity $T_e \sim I^{3/4}$ at these radii and amounts up to 3 keV at $I \approx 10^{18}$ W/cm^2 ($\tau = 100$ fs). Thermal electrons produce considerable ionization of iron ions L-shell up to formation of Li- and Be-like ions. Comparison with an experiment can be made using x-ray bremsstrahlung yield in a range of 1 – 2 keV.

Criteria of model applicability are under discussion. Outer ionization of a cluster and influence of electrons leaving ion core on cluster heating and ionization can be neglected if $0.5 >> R/r_E >> 9\omega^2/\omega_p^2$, where r_E is the amplitude of electron oscillation in laser field, ω_p is the electron plasma frequency inside a cluster.

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[3] *Kostenko O.F., Andreev N.E.* (submitted to Plasma Physics Reports).
[4] *Ditmire T., Donnelly T., Rubenchik A.M., et al.* // Phys. Rev. A. 1996. V. 53. P. 3379.

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