Seminar

Institute for Plasma Research

Title : Molecular Dynamics Simulation Study Of Resonance Absorption Phenomena In Intense Laser-Driven Atomic Nano-Clusters

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Abstract :

Laser-driven atomic clusters absorb a large fraction of laser energy (nearly 90% in experiments) compared to traditional solid/gaseous targets due to their solid-like atom density and smaller size of a few nano-meter compared to the driving laser wavelength (typically 800 nm). Various experiments on laser-cluster interaction have demonstrated that the efficient coupling of the laser energy to cluster leads to the production of energetic KeV electrons, MeV ions, MeV neutrals, X-rays and highly charged ions for rare-gas clusters which are not possible by the laser field alone. Emission of fusion neutrons due to the fusion of deuterium ions from laserdriven deuterium clusters has also shown importance. When the laser shines a cluster, atoms are ionized and a nano-plasma is formed. Electrons in the nano-plasma immediately respond to the laser field and may leave the target by absorbing laser energy. It leaves behind a plasma with a net positive charge which then Coulomb explodes, thus eventually converting induced electrostatic field energies into ion kinetic energies. Coupling of laser energy to cluster electrons can happen through collisional and collision-less processes, namely, (i) linear resonance (LR) and (ii) anharmonic resonance (AHR). This thesis considers only the above mentioned collision-less processes. During the LR which typically requires long laser pulses > 50 fs, Mie-plasma frequency ω_M of the Coulomb expanding cluster meets the laser frequency ($\omega_M=\omega$) and many electrons collectively leave the cluster by absorbing a good amount of laser energy. However, for very short infrared laser pulses of duration < 20 fs, where ion background remains almost frozen and ω_M remains much above ω (over-dense regime), LR process does not contribute and laser absorption by electrons mainly happen by AHR which occurs in the transient anharmonic potential of the charged cluster when position-dependent frequency Ω [r(t)] of each electron in the self-consistent anharmonic potential of the cluster nano-plasma satisfies Ω [r(t)] = ω. But collision-less absorption still remains to a debate.

In order to investigate the laser-cluster interaction and to understand various resonance absorption processes (LR and AHR) in greater detail, a three-dimensional molecular dynamics (MD) code with soft-core Coulomb interaction among the charge particles has been developed and exhaustively benchmarked with existing results. In the first problem, we identify AHR process as a universal dominant collision-less mechanism of absorption in an over-dense cluster irradiated by a short laser pulse. It is shown that the cluster electrons contributing to efficient absorption pass through AHR, i.e., Ω [r(t)] of electrons in the self-consistent anharmonic potential transiently meet ω and become free. MD results are corroborated further with a simple rigid sphere model of the cluster where non-interacting electrons in a predefined potential of the spherical ion background are driven by identical laser fields as in MD. In the second problem, we find the optimal regime of laser wavelength where the laser absorption, electron removal and average charge states for a laser-driven cluster are maximized for a given intensity and pulse energy due to dynamical unification of possible resonances, i.e., (i) the LR in the in the initial time of plasma creation, (ii) the LR in the Coulomb expanding phase in the later time and (iii) AHR in the intermediate time in a single short laser pulse. It is shown that for a given pulse energy and a cluster density, the efficient coupling of laser energy to cluster does not happen at the commonly expected wavelength λ_M of LR, but happens at a red-shifted wavelength that lies in the marginally over-dense band of $\Lambda d=(1-1.5)\ \lambda_M$ depending upon the percentage of electron removal from the cluster. Finally, the dependency of laser absorption and the red-shift of absorption peak on different laser and cluster parameters like peak intensity, wavelength, pulse duration, laser polarization, cluster size, and cluster type are discussed in greater details.