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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Venue : Committee Room No.3 (New building), IPR

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). The efficient coupling of laser light leads to the production of energetic KeV electrons, MeV ions (useful for driving fusion reaction with deuterium cluster plasma), generation of X-rays, and MeV neutrals in experiments. 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). During the LR which typically requires long laser pulses > 50 fs, Mie-plasma frequency ωM 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 ωM remains much above ω (overdense 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 positiondependent frequency $\Omega[r(t)]$ of each electron in the self-consistent anharmonic potential of the cluster nano-plasma satisfies $\Omega[r(t)] = \omega$. But collision-less absorption still remains to a debate, which is the central importance of the thesis. The work reported in the thesis presents laser energy absorption processes (LR and AHR) in the short pulse regime and their dependency on different laser and cluster parameters (i.e., peak intensity, wavelength, laser pulse polarization, cluster size and type etc.).

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 from scratch and exhaustively benchmarked with existing results. In the first problem, we identify AHR process as a 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., $\Omega[r(t)]$ 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 noninteracting 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 λM 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. The fact that the resonance is shifted towards a longer wavelength may be attributed to spill out of the electron density beyond the ion background in the context of typical laser-solid interaction; and this seems to be only confirmed by the present study. Finally, the dependency of laser absorption and the red-shift of absorption peak on the laser polarization for different atom cluster type is examined.