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Energy deposition of intense femtosecond laser pulses in Ar clusters

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Abstract. The transmission of femtosecond laser pulses in the Ar atomic-clusters is studied, and the absorption of the laser energy is calculated using a new theoretical model. Then the relevant physics parameters including the continuous winded range, the maximum penetration depth and the stopping time, have been calculated. Thus, we re-examine theoretically the possibility of this model.

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Key words: femtosecond laser pulses, cluster, energy deposition

1 Introduction

The advent of the chirped-pulse amplification (CPA) technique, coupled with the development of solid-state lasers capable of delivering ultra-short pulses, has opened the new field of ultrahigh-intensity laser physics. Researches on the interactions between clusters and intense femtosecond laser pulse have recently been a hot field [1-5]. The hot dense plasma created by the irradiation atomic clusters by short, intense laser pluses is a promising, compact source of x rays for applications including next generation extreme ultraviolet lithography, x-ray microscopy, ang x-ray tomography [6]. Atomic clusters formed in supersonic expansion of a high-pressure gas into vacuum have been proposed recently as an alternative solution combining the advantaged of both gaseous and solid targets. In particular, a rare-gas cluster that is classified as an intermediate state between isolated atoms and bulk solid-state matter has attracted considerable attention as a target [7], because it shows unique properties such as efficient absorption of laser photons leading to Coulomb explosions of a cluster [8], generation of bright x-ray radiation [9] and

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highly charged atomic ions, and formation of energetic ions up to MeV. For large clusters, Ditmire *et al*. demonstrated DD fusion induced by the Coulomb explosion of deuterium clusters in a field of 10^{16}W/cm^2 [10].

The interaction of ultraintense laser pulses and gas clusters contains three processes: the atom ionization, the energy absorption of laser pulses, and the Coulomb explosion of the clusters. There are many mechanisms to explain these processes, however, each model can fit the phenomena partly, a more detailed model of the laser-cluster interaction is required. When Ar clusters with 5×10^4 atoms and the radius of 13.4 nm irradiated by ultraintense ($I \geq 10^6$ W/cm^2) and ultrafast (duration $\sim$ 10-100 fs) laser pulses, the charged atom ions can up to Ar^{8+} [11]. And above 90% of the laser energy is transferred to the kinetic energy of the cluster plasma [12, 13]. In this article, the transmission of femtosecond laser pulses in the Ar atomic-clusters is studied. Ultraintense laser can produce the relativistic electron beam (REB) and then the REB energy is delivered to the plasma. Then the relevant physics parameters including the continuous winded range, the maximum penetration depth and the stopping time, have been calculated. Thus, we re-examine theoretically the possibility of this model.

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2.1 Main energy loss mechanism [14]

The REB energy range considered is fixed by the laser irradiance through the relationship

$$T(keV) = 511\{[1+0.007(I/I_{16})\lambda_\mu^2]^{1/2}-1\} \tag{1}$$

where, λ_μ is laser wavelength in unit of μm. Here we assume $\lambda_\mu = 1\mu$m. I_{16} is the laser intensity 10^{16} W/cm^2. When the laser pulse is in the range of $10 \leq I/I_{16} \leq 100$, we can obtain the REB energy within the scope of $17.6 \leq T$(keV)≤ 155.

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The energy loss of the incident electron as a result of interaction with the free electron in the plasma may be calculated using Möller's cross section

$$(\frac{d\sigma}{d\varepsilon})^- = \frac{\chi}{E_0}[\frac{1}{\varepsilon^2}+\frac{1}{(1-\varepsilon)^2}+(\frac{\gamma-1}{\gamma})^2\frac{2\gamma-1}{\gamma^2}\frac{1}{\varepsilon(1-\varepsilon)}] \tag{2}$$

where

$$\chi = \frac{2\pi r_0^2 m_e c^2}{\beta^2}, \ r_0 = \frac{e^2}{m_e c^2}$$