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High Power Laser-Plasma Interaction under a Strong Magnetic Field

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Abstract

Existence of a magnetic field can largely affect the nature of laser (electromagnetic wave) propagation in plasmas. Recently, generation of an extremely strong magnetic field, which is of the order of kilo tesla, have been achieved in laboratory experiments by using high intensity lasers (Yoneda et al. 2012; Fujioka et al. 2013; Korneev et al. 2015). Because the laser wavelength is typically about 1 micron, the cyclotron frequency of electrons ω_{ce} for a kilo tesla field is comparable to the laser frequency ω_L. Interestingly, when $\omega_{ce} > \omega_L$, the cutoff frequency disappears for the whistler mode, and then the laser light can travel into overdense plasmas. Thus, the critical field strength defined as $B_c \equiv m_e \omega_L / e$, where m_e and e are the electron mass and the elementary charge, has a crucial meaning in laser-plasma interaction just like the critical density for non-magnetized plasmas. It can be expected that the direct interaction between a high intensity laser and overdense plasma could bring a new mechanism of efficient plasma heating and particle acceleration, and have various applications such as the inertial fusion science, laser-driven ion beams for cancer therapy, and astrophysical cosmic-ray acceleration.

We investigate laser-plasma interactions under a strong magnetic field by one-dimensional Particle-in-Cell (PIC) simulations. A simple setup is considered in our analysis, in which a thin foil of solid hydrogen is irradiated by a right-handed circularly polarized laser. A uniform magnetic field is assumed in the direction of the laser propagation. Then the whistler wave can penetrate the overdense hydrogen plasma when the external field is larger than the critical B_c. In this situation, key parameters are the plasma density and the size of the external field. We performed various models in the density-field strength diagram, which is actually the so-called CMA diagram, to evaluate the efficiency of the energy conversion from the laser to plasma and the reflectivity and transmittance of the laser.

It is found that there are two important processes in the interaction between the whistler wave and overdense plasma, which are the cyclotron resonance of relativistic electrons and the parametric (Brillouin) instability. The electron energy increases significantly through the resonant absorption, when the external field strength is near the critical value B_c. If the laser intensity is high enough, the electron velocity driven by the laser electric field can be relativistic. This fact should be considered in the cyclotron resonance condition, and which causes the realization of wider range of resonant field strength. Because of the high temperature of electrons, ions are accelerated dramatically by a large sheath field. The excitation of a large-amplitude ion acoustic wave by the stimulated Brillouin scattering is also very important for both the energy conversion and reflectivity. This could be an efficient mechanism for the ion heating directly from the laser energy.