Shock Wave Particle Acceleration in Laser-Plasma Interaction

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Numerous processes from the bow-shock in the earth's magnetosphere to the blast wave in supernova explosions are accompanied with collisionless shocks that can accelerate particles to high energy [1]. In the laboratory high energy particles also can be generated by collisionless shocks. Recent experiments and simulations have demonstrated effective CO_2 laser acceleration of quasi-monoenergetic protons from thick gaseous hydrogen target (of thickness tens of laser wavelength) via hole boring and shock accelerations [2]. Laser proton acceleration has been a subject of great interest because of its high acceleration gradient ($\sim 10\,\mathrm{GeV/cm}$) and its potential of leading to the development of table top ion accelerators and its associated wide range of applications.

We propose a scheme of combining the laser radiation pressure acceleration (RPA) with the shock acceleration by irradiating lasers on thin gaseous targets, with thin gas targets thickness of a few laser wavelengths. Laser can compress it to form a shock and to accelerate it as a whole, in the light-sail fashion, with the protons trapped in it. Thus proton acceleration is a combination of radiation pressure acceleration and shock acceleration, with the RPA being the dominant acceleration mechanism at later stage.

To demonstrate the proposed acceleration scheme, we performed a series of two-dimensional (2D) particle-in-cell (PIC) simulations with CO_2 irradiation on laser thin gas target with the dimensionless laser amplitude $a=eE/m_ec\omega$ varying from 1.2 to 10, where m_e, c, ω, and E are the electron mass, the light speed in vacuum, the laser frequency and the laser electric field amplitude, respectively. The incident laser is a circularly polarized wave with Gaussian shape in both directions. The target density n_0 varies from $2n^*$ to $10n^*$, where $n^*=1.1\ 10^{19}\ cm^{-3}$ is the critical density. The target has triangular shape.

The laser radiation pressure compresses the gaseous plasma into a sharp density peak, that propagate as shock front with Mach number $M=1.3$. The protons behind the shock front are accelerated by reflection of and the compressed proton layer is of sub-wavelength thickness with the peak density reaching hundreds of the critical density. The laser radiation pressure not only compresses the plasma, but also accelerates the high density layer and traps protons in it. The radiation pressure accelerated proton layer quickly catches up with the shock accelerated protons. The compressed thin layer of protons is overdense and therefore can be accelerated by the laser radiation pressure until the development of the Rayleigh-Taylor instabilities [3] that destroys the opacity of the compressed layer.

References

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