QUASY-MOMOENERGETIC ION BUNCH GENERATING BY TWO STAGE LASER ACCELERATION

G. Dudnikova[#], UMD, College Park, USA
D. Gorpinchenko, ICM&MG SBRAS Novosibirsk, 630090, Russia

Abstract

A scheme is proposed for producing a quasi-monoenergetic ion bunch by irradiating a foil with two subsequent laser pulses-a prepulse followed by a stronger main pulse. We have demonstrated a possible mechanism for generating a quasi-monoenergetic ion bunch from a homogeneous target consisting of atoms of the same species by the two-stage acceleration. Results are presented from 2D and 3D PIC simulation that illustrate the scheme and determine the space-time and energy characteristics of the accelerated ions. Investigation was made by varying such control parameters as the duration and amplitude of the main laser pulse and the prepulse, the time lag between the pulses, and the thickness and density of the foil.

INTRODUCTION

Successful experiments carried out in recent years on the irradiation of foils by short intense laser pulses show that the ions can be accelerated to high energies [1]. The energy spectrum of these ions is typically broad and has a cutoff at certain energy. However, practical applications require not only that the ion energies be high but also that the beams of accelerated ions be monoenergetic. This is why one of the challenging problems in high-energy density laser physics is to develop methods for generating such beams. Quasi-monoenergetic ion bunches have recently been produced in a number of experiments [2]. Recall that the mechanism for producing a quasimonoenergetic light ion bunch is associated with the spatial separation of light and heavy ions. In the initial stage, the laser pulse generates fast electrons at the front of the target. Fast electrons then escape from the foil in the forward direction, giving rise to a charge-separation electric field, which accelerates light ions most efficiently while heavy ions are accelerated at a far slower rate and move behind the light ones. As time progresses, the fastest of the heavy ions begin to catch up with the slowest of the light ions. The Coulomb repulsive force between the two groups of the ions gives rise to a strong electrostatic field at the front of heavy ions. This field in turn additionally accelerates light ions and acts as a Coulomb "piston" to form a quasi-monoenergetic light ion bunch. Of course, this acceleration scenario applies also to the ions of the same species, provided that they are preseparated into a fore, slower group and a rear, faster group. In this case, the faster ions can catch up with the slower ions to produce from them a quasi-monoenergetic bunch. The ions of the same species can be separated into a slower and a faster group by using two subsequent laser pulses-the first, weaker, seed pulse is followed by the second, stronger, main pulse. The objective of the paper is to provide mechanism for accelerating ions of the same species from a homogeneous target irradiated by two subsequent laser pulses.

TWO STAGE ION ACCELERATION

We carried out sets of particle-in-cell simulations with the latest version of the UMKA2D3V computer code [6]. The geometry of the problem and the laser-plasma parameters are as follows. In a computation region (x, y) having a rectangular shape ($0 < x < 70\lambda$, $0 < y < 50\lambda$, with λ being the laser wavelength), there is a hydrogen plasma layer consisting of a high-density foil and a preplasma, which models the nonideal nature of laser radiation (the finit intensity contrast ratio). The density of the preplasma increases exponentially from zero (at $x = 5\lambda$) to $n_e = 4n_c$ at the foil surface ($x = 20\lambda$). The thickness of the foil is 2λ and its density is equal to $n_e = 4n_c$, where n_c is the critical plasma density. Two subsequent laser pulses having Gaussian profiles in both the longitudinal and transverse directions enter the computation region through its left boundary and are incident normally on the foil surface. The time lag between the pulses is $50\lambda/c$, where c is the speed of light. The longitudinal and transverse dimensions of the laser pulses are the same and are equal to 100λ and 8λ for the prepulse and the main pulse, respectively. The intensities of the pulses correspond to the values $a = 1$ and $a = 5$ of the standard dimensionless vector potential and, accordingly, to intensities of 1.37×10^{18} and 3.4×10^{19} W/cm^2 for the laser wavelength $\lambda = 1\mu$m. Here, a= eE /mcω, where E is the laser electric field amplitude, ω is the laser frequency, and m is the mass of an electron.

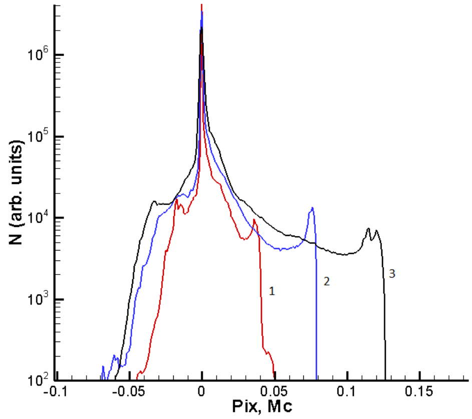

Figure 1: Spectra of ions accelerated by a seed pulse (a=1) and a main pulse (a=5) at dimensionless time tc/λ=125 (1), 150 (2), 200 (3).

The calculated distributions of the forward accelerated ions over the longitudinal momentum P_{ix} are presented in Fig. 1. For comparison, in Fig. 2 we show the same distributions but calculated for a single laser pulse having the same intensity, 3.4×10^{19} W/cm^2, as the main pulse in the previous case (a=5). By the time $t = 100\lambda/c$, a well-pronounced quasi-monoenergetic component corresponding to a bunch of accelerated ions has already formed in the ion spectrum. For a single laser pulse (Fig.2), no quasi-monoenergetic ions are observed, so we can conclude that they are generated by the two-stage mechanism, when the ions are accelerated first by the seed pulse and then by the main pulse.

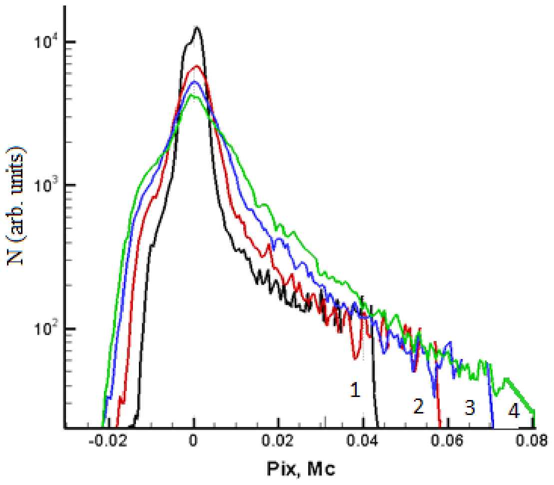

Figure 2: Spectra of ions accelerated by a single pulse (a=5) at dimensionless time tc/ λ=120 (1), 150 (2), 200 (3), 250 (4)

Fig. 3 illustrates how the ions that occur near the axis of the propagating laser pulse are distributed over the phase plane (x, p_{ix}). We can observe a bunch of high-energy ions propagating from the target and also the sharp bunch front, near which breaking occurs. A high-energy ion bunch is also clearly seen in Fig. 3, which displays the spatial ion distributions behind the target at successive times. Initially, a bunch of fast ions is fairly dense but its charge is neutralized incompletely, so its spectrum broadens under the action of Coulomb repulsive forces. The bunch then becomes less dense and its charge is neutralized to a greater extent because of the adiabatic cooling of the electrons.

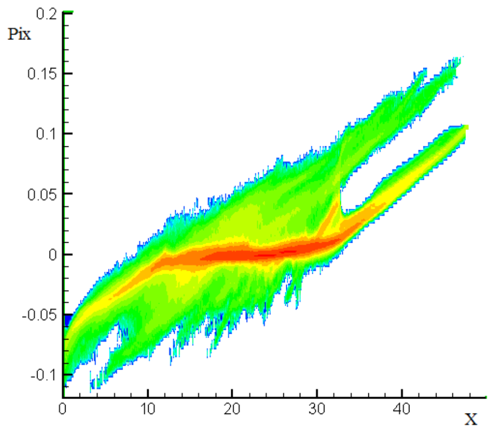

Figure 3: Ion phase space at t=275.

Hence, we have demonstrated a possible mechanism for generating a quasi-monoenergetic ion bunch from a homogeneous target consisting of atoms of the same species by the two-stage acceleration with two subsequent laser pulses. The aim of the present report is not to give a comprehensive analysis yielding the optimum conditions for producing the highest quality ion bunches but merely to prove the viability of the proposed ion acceleration mechanism. The relevant detailed investigation can be made by varying such control parameters as the duration and amplitude of the main laser pulse and the prepulse, the time lag between the pulses, and the thickness and density of the foil. By varying these parameters, it is also possible to separate out the ions with a desired energy. A detailed and comprehensive analysis of the proposed mechanism for producing quasi-monoenergetic ion bunches is important for further development and improvement of laser methods for particle acceleration.

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