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3.5 Energetic-Particle Generation Driven by The Ultrafast, Ultrahigh-Intensity Ti:sapphire Laser

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We have examined the interaction of intense laser fields with Xe clusters by measuring the energy distributions of emitted ions using the ultrafast 20-fs laser pulses. This work demonstrates that the energetic-particle emission can be optimized by manipulating the characters of the ultrafast laser pulses, i.e. the pulse duration and sign of chirp.

Keywords: Cluster, High power laser, Energetic-particle, Frequency chirp

1. Introduction

The development of ultrafast, high peak-power laser systems enables us to investigate behaviors of matter under extreme conditions. In the last decade, extensive studies on interactions of the intense laser fields with atoms, molecules, and clusters in the gas phase as well as with solid-state targets have been performed. In particular, the interaction of such fields with noble-gas clusters with typical sizes of several or tens of nanometer is found to exhibit distinctive features from other targets, because the clusters have the density of a solid, even though the volume average density of the cluster ensemble is low [1]. The clusters absorb most of the incident laser energy (> 95 %), which leads to heat up the clusters significantly and to a number of characteristic phenomena such as enhanced emissions of x rays in the 0.1-10 keV range, and generations of energetic electrons and highly energetic multiply-charged ions as high as few keV and 1 MeV, respectively [2]. They are expected to utilize as debris free sources of intense x rays for a biological imaging and for a nano-lithography as well as an ion source for a particle acceleration, and even a fusion research. In order to understand the laser-cluster interaction, it is important to explore the optimal conditions to maximize the emitted particle energies and x-ray yields. In this work, we have measured the energy distributions of emitted ions by manipulating the pulse duration and sign of chirp under the fixed laser peak intensity of 2×10^{17} W/cm^2.

2. Experiments

The laser used is a high peak-power Ti:sapphire laser based on the technique of chirped pulse amplification, which was developed at JAERI [3] and gives a transform-limited pulse duration of 20 fs, a center wavelength of 800 nm, and a maximum compressed energy of 1.9 J. The ultrafast light pulses were focused by using an Au-coated off-axis parabolic mirror (f=161 mm) in an ultrahigh vacuum (2×10^{-8} Torr) target chamber. The measured spot size was 12 μm at $1/e^2$. Xe clusters were produced by expanding high-pressure (1 Mpa) Xe gases into a cluster-source chamber as a supersonic jet using a pulsed nozzle with an orifice diameter of 500 mm, and introduced to a laser-cluster interaction region through a skimmer with an orifice diameter of 500 mm. An average size of the clusters was estimated in a range of 5.5×10^4 atoms per cluster using the Hagena's empirical scaling parameter. The kinetic energies of the multiply-charged ions ejected from the laser-cluster interaction region were determined by measuring their flight times. The laser pulse duration was varied from 20 to 600 fs by introducing chirp by changing the distance between a grating pair in the pulse compressor, and simultaneously the laser energy was changed to keep the peak intensity fixed. It should be noted that depending on the direction of movement with respect to the original position of the grating, which gives a transform-limited 20-fs pulse, two types of chirped pulses having the same pulse duration but different sign, i.e. positively (+ sign) chirped pulse and negatively (- sign) chirped pulse, are obtained.

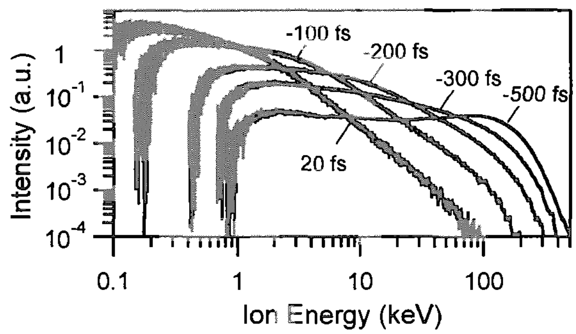

Fig. 1. Ion Energy distributions of the emitted ions calculated from the ion TOF spectra, obtained when the Xe clusters were irradiated by the various laser pulse chirps at the fixed peak intensity of 2×10^{17} W/cm^2.

3. Results

Figure 1 shows the energy distributions of the emitted multiply-charged ions when the Xe clusters were irradiated by the various laser pulse chirps. These spectra were obtained by directly translating the Time-of-flight (TOF) spectra into an energy distribution function for the ions using the relation,

$$f(E) = f(t)(dE/dt)^{-1} = f(t)m_i^{-1}l^{-2}t^3,$$

where m_i is the ion mass, l the length of the flight tube, and t the flight time. When the Xe clusters were irradiated by the 20-fs pulse with the laser energy of 2.6 mJ, the energy distribution with the bulk component less than ~1 keV was obtained. As the pulse duration became longer, the energy distributions shifted to higher energies, and almost flat distribution was established for the 500-fs pulse with the laser energy of 66 mJ. In order to elucidate the importance of the laser pulse duration and sign of chirp to the laser-cluster interaction, the mean ion energy $\overline{E}$ defined as,

$$\overline{E} = \int Ef(E)dE / \int f(E)dE,$$

was evaluated from the ion energy distributions and compared as a function of the pulse duration

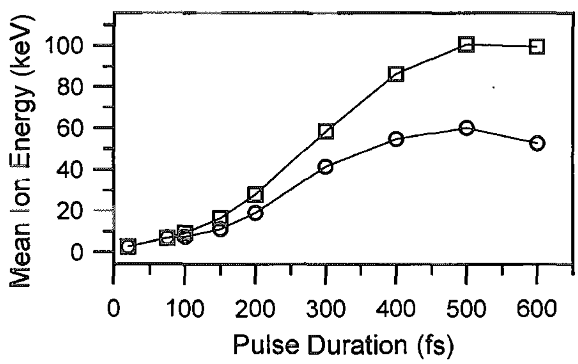

Fig. 2. Mean ion energies calculated from the ion energy spectra for various laser pulse chirps at the fixed peak intensity of 2×10^{17} W/cm^2. Open squares and circles represent the mean ion energies obtained with negative and positive chirps, respectively.

in Fig. 2. The uncertainties in the $\overline{E}$s thus obtained are estimated to be less than ±4 %. When the Xe clusters were irradiated by the 20-fs pulse with the laser energy of 2.6 mJ, $\overline{E}$=2.6 keV was obtained. The mean ion energies obtained by the irradiation with both positive and negative chirp increased gradually at the same rate with the increase in pulse durations up to 100 fs. After that, the meanion energy obtained with negative chirp began to rise sharply and exceeded that with positive chirp. They reached the peak of the pulse duration at 500 fs with the laser energy of 66 mJ. The maximum value of the mean ion energy obtained in this work is $\overline{E}$=101 keV for the 500-fs pulse with negative chirp as the optimal condition. This energy is about 1.6 times larger than that with positive chirp ($\overline{E}$=62 keV), and is also about 40 times as large as that obtained by the 20-fs pulse ($\overline{E}$=2.6 keV) under the same laser peak intensity of 2×10^{17} W/cm^2.

These results clearly demonstrate that the energetic ion emission can be optimized by manipulating the characters of the ultrafast laser pulses, such as the pulse duration and sign of chirp.

References

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