Improved Characteristics of Laser Source of Ions Using a Frequency Mode Laser

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Abstract. We used a mass-spectrometric method to investigate the characteristics of laser-produced plasma ions depending on the nature of the target and on the parameters of the laser radiation. Experiments are carried out on porous Y_2O_3 targets with different densities ρ, subjected to a laser radiation, where the laser works in a frequency mode (ν=1-12 Hz). We found that the laser frequency has a significant effect on the parameters of plasma ions: with increasing the frequency of the laser the charge, energy and intensity of ions increase for a given parameters of the target. This effect is more pronounced for small densities of the target. We related these two effects to a non-linear ionization process in the plasma due to the formation of dense plasma volume inside the sample absorbing the laser radiation and to the change of the focusing conditions in the case of the frequency mode laser.

Keywords: laser-produced plasma, two-element target, mass-spectrometer

Introduction

Many theoretical and experimental works have been devoted to study formation and expansion of the plasma ions from the surface of solid targets under the action of powerful laser radiation. Most of these investigations were devoted to study laser-produced plasma ions as a source of charged particles to be used for the Inertial Confined Fusion [1-3]. However, for the practical use of these charged particles one should be able to control the charge and intensity of ions. The latter can be done e.g. by changing the composition of the targets [4-6]. It was shown experimentally [4] that the parameters of plasma ions generated from the surface of four component $YBa_2Cu_3O_7$ target considerable differ from the one obtained from the targets of the same elements (i.e. Y_2O_3 and Cu_2O_3), which was explained by the increase of the recombination processes in the multi-element plasma. It is not an easy task to take into account all the processes taking place in the plasma due to the presence of ions of different mass in the above experiment. Therefore in our recent work [5] we considered a simpler case – plasma formation process on the surface of two-element PbMg target – where the interaction of different kinds of ions can be easily taken into account. We have shown that the energy spectra of both light (Mg) and heavy (Pb) ions are enlarged compared to the spectra of one-element plasma due to the energy exchange between the ions. For example, the increase of Mg concentration leads to the enlargement of Pb ions energy for two times and the ions' impulse duration for more that 5 times compared to one element targets.

The characteristics of plasma ions can also be improved by using porous targets of different density. In Ref. [6] two-element laser-produced plasma ions generated from porous (Ho_2O_3) target were studied depending on the target density (ρ) by mass-spectrometric method. Experimental results have shown that at low energy part of the spectra maximal charge for oxygen ions is reached at low densities, while maximal charge of *Ho* ions is obtained at higher target densities. This effect was related to non-equilibrium ionization processes in the plasma due to the changing of the volume, which absorbs laser radiation.

It is known that many properties of laser-produced plasma ions strongly depend on the parameters of the laser system, such as the intensity and wavelength of the radiation, angle of interaction, focusing condition, etc. In our previous work we have investigated multi-charge ions generated from the surface of Al target under the action of laser radiation from the laser source working in the frequency mode with frequencies ν=1 – 12 Hz [7]. We have shown experimentally that with increasing the frequency of the laser (at constant intensity of laser radiation q) the intensity of Al^{1+} ions increases linearly, while nonlinearity is found in the dependence of the energy and intensity of highly charged ions on the frequency of the laser. The latter effects were related to considerable changes in the focusing condition of the laser radiation and ionization processes on the surface of the target. We would like also to mention that most of the drivers in Heavy Ion Synthis scinarion (lasers, heavy ion accelarators, Z-pinches) work in the pulsed regime with frequencies 1-10 Hz [8].

Experimental setup

Experiments have been carrier out in a laser mass-spectrometer with electrostatic mass-analyzer (see Ref [6] for more detail). Emitted from the surface of targets ions are detected at the distance 100 cm, where the size of the slots for ions entry and exit for time-of-flight analyzer were 0.4 mm. Neodymium glass laser working with frequencies ν=1-12 Hz has been used in the experiments and the laser radiation was directed perpendicular to the surface of the targets. The duration of the laser impulse was 15 ns and the maximal intensity of the laser radiation on the surface of the target was q= 10^{11} W/cm^2. Experiments are carried out in the same initial conditions (vacuum (10^{-6} Tor.), the position of the targets, focusing condition of the laser radiation, parameters of the mass-spectrometer, registering techniques of ions etc). The energy of the laser radiation is measured by optical filter and controlled by photoelectrical detector. Peak intensity of the laser radiation in the frequency mode fluctuated within 5%. In the experiments we have used porous Y_2O_3 targets in the form of a disk of radius 0.5 cm and thickness 5 mm, with densities ρ_0=1.2 g/cm^3, ρ_1=1.4 g/cm^3, ρ_2=2.8 g/cm^3, ρ_3=3.2 g/cm^3, ρ_4=3.6 g/cm^3 and ρ_5=3.7 g/cm^3. Here we present our results obtained for the intensity of the laser radiation q= 10^{11} W/cm^2.

Experimental results

We obtained experimentally mass-charge spectra, i.e. time-of-flight spectra, of multi-charged Y and O ions for different density of targets ρ and for the frequency of the laser ν=1-12 Hz. These results show that at small target density oxygen ions have largest charge and they are well separated from Y ions. The increase of the target density leads to the decrease of the charge of O ions and multi-charged Y ions appear in the mass-specters as we have shown earlier [6]. The frequency of the laser also has a strong effect on the parameters of the plasma ions: for low target density ρ the increase of ν leads to the increase of both charge and intensity of the ions, while for larger density of the target the charge of the heavy ions remain unchanged and the charge of the light ions slightly increase.

From the obtained mass-charge spectra of ions we constructed energy distribution of ions depending both on the target density and the laser frequency. Fig.1. shows the energy spectra of laser-produced plasma ions for $\rho=\rho_0$ (a) and $\rho=\rho_3$ (b) obtained in the mono impulse regime (ν=1 Hz). As we have mentioned above, for $\rho=\rho_0$ O ions has largest charge multiplicity (Z_{max}=4) and they are mostly located in the low energy part of the spectrum (Fig. 1 (a)). Y ions occupy large region in the spectra, due to their heavier mass, and the maximal charge of these ions equals to 3. With increasing the target density O ions with larger charge disappear from the spectra and the energy range of these ions slightly decreases (see Fig. 1 (b)). The maximal charge of Y ions does not change here with increasing ρ and it equals to Z_{max}=3. The increase of ρ leads to the widening of the energy spectra of Y ions for all the charge multiplicity. This effect is the result of non-equilibrium ionization processes in the plasma due to the formation of dense plasma inside the target, which effectively absorbs the laser radiation. Namely, for low target density, when there are more granules in the target, most of the laser radiation enters deep inside the sample, where the recombination mostly takes place for Y ions. For larger ρ the laser radiation mostly interacts with the surface of the sample, where ionization of Y ions dominates. We have also found that characteristics of plasma ions do not change with further increase of the target ($\rho>\rho_3$) in the mono-impulse regime.

Let us now consider the effect of the laser frequency on the energy distribution of the plasma ions. Here we give our results for larger density of the target, so that we neglect the influence of ρ. Fig.2. shows the energy spectra of ions in Y_2O_3 plasma obtained for the laser frequency ν=3 Hz for two different values of ρ. As we showed above, for $\rho=\rho_3$ (Fig.2 (a)) O ions are located in a narrow range of the energy (20-200 eV) and their maximal charge is unchanged compare to lower density case (see Fig.1 (b)). Y ions are located in the energy interval 20-800 eV with Z_{max}=3. This small increase of the laser frequency affects only on the intensity of the ions: O ions of both charge increases, while the intensity of heavy ions considerably decreases with increasing ν.

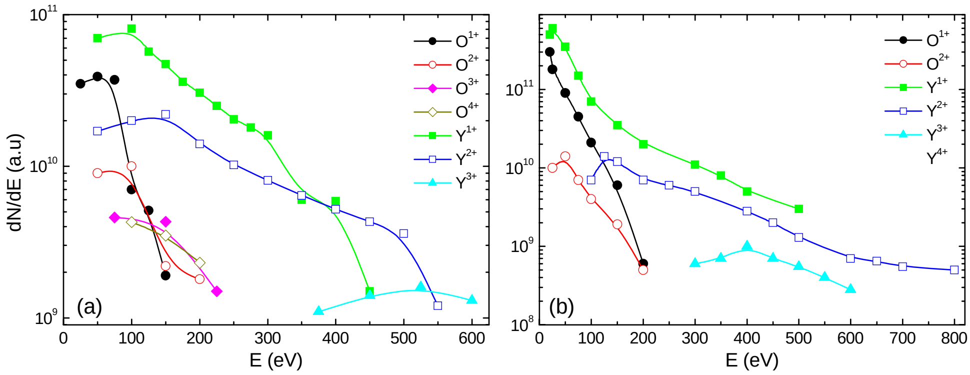

Figure 1. The energy spectra of ions from two-element Y_2O_3 plasma obtained for $\rho=\rho_0$ (a) and $\rho=\rho_3$ (b) at ν=1Hz.

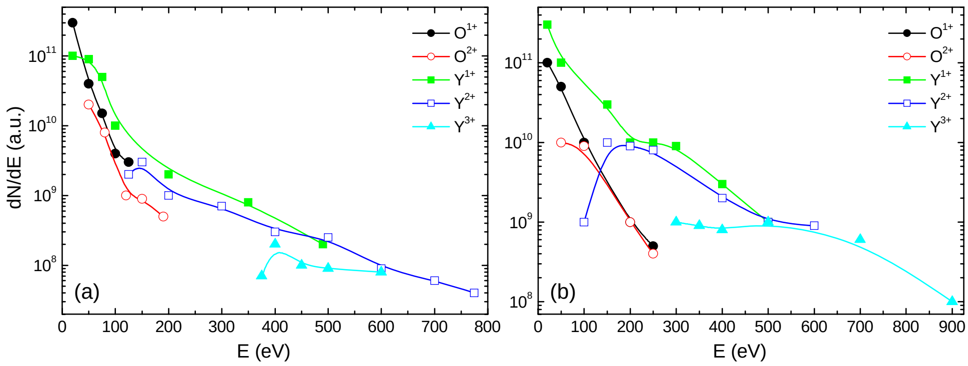

Figure 2. The energy distribution of ions in two-element Y_2O_3 plasma obtained at ν=3 Hz and for two different target density: $\rho=\rho_3$ (a) and $\rho=\rho_5$ (b).

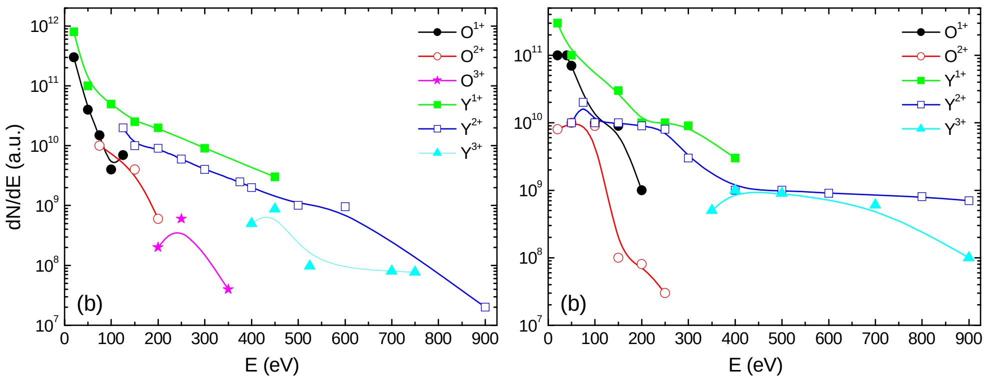

Figure 3. The same as Fig. 2, but for ν=10 Hz.

Fig.3 (a) shows the energy spectra of ions obtained for larger frequency of the laser (ν=10 Hz) and for $\rho=\rho_3$. The effect of the laser frequency is quite evident from this figure. First, O ions with charge Z=3 appears in the spectra. Second, the energy spectra of both light (O) and heavy (Y) ions expand to higher energies. Now O ions can be detected in the energy interval 20-350 eV and Y ions in the energy range 20-

900 eV. At the same time the intensity of both kinds of ions for all charge multiplicity decreased with increasing ν.

Further increase of the laser frequency ν has less influence on the ions parameters for larger target density. In this case charge composition of ions is not affected by the laser frequency and the maximal energies and intensity of the ions are also not changed. Only ions with small charge are affected by ν: the width of their energy spectrum is decreased, while this width increased for the ions of larger charge. For all the values of the frequency ν the energy spectrum has a maximum and it shifts towards higher energies with increasing the charge of the ions.

Discussion

One of the main results of our experiment is the change in the amplitude and charge of ions' currents at different density of the targets and the frequency of the laser radiation. The effect of the target density is explained by the formation of the dense plasma inside the target (due to the granular structure), which strongly absorbs the laser radiation. This effect decreases for larger target density where the laser radiation mostly interacts with the surface of the target.

We have found that the charge composition and the total current of the ions are strongly affected by the frequency of the laser. This is, to our understanding, due to the change of the focusing condition of the laser radiation on the surface of the targets. The radiation of the laser working in the frequency mode does not only heats the surface of the target but it also forms craters with noticeable sizes, which can strongly change the focusing condition of the laser radiation during the interaction process [9]. The later is due to the fact that the ionization process and the expansion of multi-charge ions take place at small time interval than the time between the impulses and additional thermal processes take place on the surface of the target. It was found that [7] the maximal charge of ions is obtained not for the exact focusing, but at small shift of the focal spot from the surface of the target. Therefore, by the change in the focusing condition – the place of the focal spot or formation of craters, as well as using laser in frequency mode, one can control charge and energy spectra of ions obtained from the surface of two-element targets under the action of laser radiation.

Summary

We have experimentally studied the effect of the laser frequency on the formation of energy spectra of ions from two-element porous targets. In the mono impulse regime of the laser the parameters of the plasma ions strongly depend on the target density: for small ρ light elements of the target has maximal energy and with increasing ρ both their charge and the energy decreases considerably; ions of heavy component of the target has smaller charge for low density of the target and both the charge and the energy of these ions increases with ρ. However, starting from some value of the target density the parameters of plasma ions remain unchanged. We have shown that with increasing the frequency of the laser the charge, energy and intensity of ions increase for a given parameters of the target. Although, this effect is more pronounced for small densities of the target, significant influence of the laser radiation is observed for larger values of the target density. We related these two effects to a non-linear ionization process in the plasma due to the formation of dense plasma volume inside the sample and to the change in the focusing condition of the laser radiation due the formation of clusters on the surface of the target.

Acknowledgments

This work is supported by IAEA (contract UZB- No: 13738). Author acknowledges G.R. Berdiyorov for his discussions.

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