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Mass-charge and energy spectra of oxygen ions in a two-element laser-produced plasma

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Abstract

Using a static mass-spectrometer we study multi-charge plasma ions generated from solid targets under the action of the laser radiation. We consider two-element Se_2O_3, Ce_2O_3 and Lu_2O_3 targets with main attention to the properties of oxygen ions. Oxygen ions are obtained in the range of the energy E=40-250 eV with maximal charge Z_{max}=2, which is independent on the target composition for the given intensity of the laser radiation. However, the properties of the energy spectra of oxygen ions strongly depend on the second component of the target, which is explained by the interaction between the light (O) and heavy (Sc, Ce, Lu) elements of the target.

Introduction

It is know that one of the main problems facing thermonuclear fusion is to find a source of ions having characteristics suitable for ICF [1,2]. Laser source of ions can provide the highest intensity of multiply charged ions for injection into practically any accelerator [3,4]. For the practical use of these sources it is desirable to have high momentum without reduction in intensity and charge of ions. One of the ways to increase the momentum of ions is to use multi-element targets. It has been demonstrated that the energy spectra of ions obtained by laser irradiation of multi-element targets appreciably differ from the spectra of ions obtained from single element targets [5-7]. In Ref. [7] two-element PbMg targets were investigated where the concentration of light element Mg was fluently changed. It was shown that the energy spectra of both light and heavy ions were enlarged compared to the spectra of one-element plasma due to the energy exchange between light and heave ions. For example, the increase of Mg concentration leads to the enlargement of energy spectra of Pb ions for two times and the impulse duration for 3-10 times compared to one element targets. In Refs. [8] 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 ($E \leq 50$ *eV*) maximal charge for oxygen ions is reached at low densities (ρ_1, ρ_2), while maximal charge of *Ho* ions is obtained at higher target densities ($\rho \geq \rho_3$). This effect is the results of non-equilibrium ionization processes in the plasma due to the changing of the volume, which absorbs laser radiation.

In this work we study parameters of the plasma ions generated from the surface of two-element (Se_2O_3, Ce_2O_3, Lu_2O_3) targets under the action of the laser radiation using the mass-spectrometric method. As oxygen atoms are present in most of the targets used in such experiments, we mainly focus on the properties of oxygen ions. Mass-charge and energy distribution of O ions strongly depend on the nature of the second component of the target, which is due to the mutual interaction of the target components.

Experimental setup

Experiments were carried out on a static laser mass-spectrometer with mass resolution of $m/\Delta m$ ~100 and time-of-flight distance L=100 cm (see Ref. [7] for more detail). The Neodymium glass laser, working in the frequency mode was used in experiments and the laser beam was directed perpendicular to the surface of the target. The duration of the laser

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impulse is 15 ns and the power density of the maximal laser radiation at the target surface is $q=10^{11}$ W/cm^2. The peak power of laser radiation varied within 5 % and each experimental data are averaged over five impulses of the laser radiation. All experiments were carried out at the same inertial conditions (vacuum (10^{-6} Tor.), focusing condition of laser radiation, parameters of electrostatic mass-spectrometer, *etc.*). The construction of the target chamber allows one to put 10 targets with diameter 10 mm and change the place of interaction of laser radiation with target. The following targets have been used in the experiments: Ce_2O_3, Se_2O_3, Lu_2O_3

Results and discussion

Experimentally we obtained mass-charge spectra of ions in two-component laser-produced plasma. The O ions with maximal charge Zmax=2 are observed at low energies of the ions and these peaks in the spectra disappears at higher energies. The ions of the second component of the target with maximal charge (Z_{max}=3) are obtained in higher energy part of the spectra. The intensity of O ions strongly depend on the target composition (especially in low energy part of the spectra), e.g. it decreases with increasing the mass of the second component of the target. We note that maximal charge of both light and heavy component of ions does not depend on the nature of two-element targets for a given intensity of the laser radiation.

From the obtained mass-charge spectra we constructed energy distribution of the ions, which allows us to study the effect of target composition on the parameters of plasma ions. Fig. 1 shows the energy spectra of ions from Sc_2O_3 (a) and Lu_2O_3 (b) plasma. As seen from this figure plasma ions have a wide energy spectrum with a single maximum of the distributions. The latter indicates that the process taking place in two-element plasma can be divided into to stages: at the first stage (before the maximum) intense ionization takes place, which is accompanied by the formation of muti-charged ions of both O and Sc (Ce, Lu); the second stage (after the maximum) is characterized by the increase of recombination process as well as by the energy exchange between light (O) and heavy (Sc, Ce, Lu) ions of two-component plasma, which qualitatively agrees with the theoretical results for the expansion of two-component plasma in vacuum [9]. It is also seen that the spectrum consists of two packages of ions located in different ranges of the energy. O ions with charge Z=1,2 are located in low energy part of the spectra, while Sc and Lu ions are located in higher energy part. There is also an overlap of energy spectrum of O ions and Sc (Lu) ions. The maximal energy of the second component of the target for all charge multiplicity of ions increases with increasing the mass of the ions. It is noticeable that the increase of the mass of the second component of the target leads to considerable changes in the spectrum of O ions. For example, the intensity and the maximal energy of O ions increase with increasing the mass of the second component of the target, which is due to the energy exchange between heavy and light components of the plasma.

Let us now consider the effect of the second component of the target to the energy distribution of O ions in more detail. Fig.2 (a) shows the energy spectra of O^{1+} ions in the two element Se_2O_3, Ce_2O_3 and Lu_2O_3 plasma. As we mentioned above character and the width of the energy spectra of O ions and the maximal energy depends on the nature of the target. Single charged O^{1+} ions have a narrow energy interval (Emax≤100 eV) for small mass ratio (i.e., Sc ions) (solid curve in Fig. 2 (a)). With increasing the mass of the second component (Ce ions)

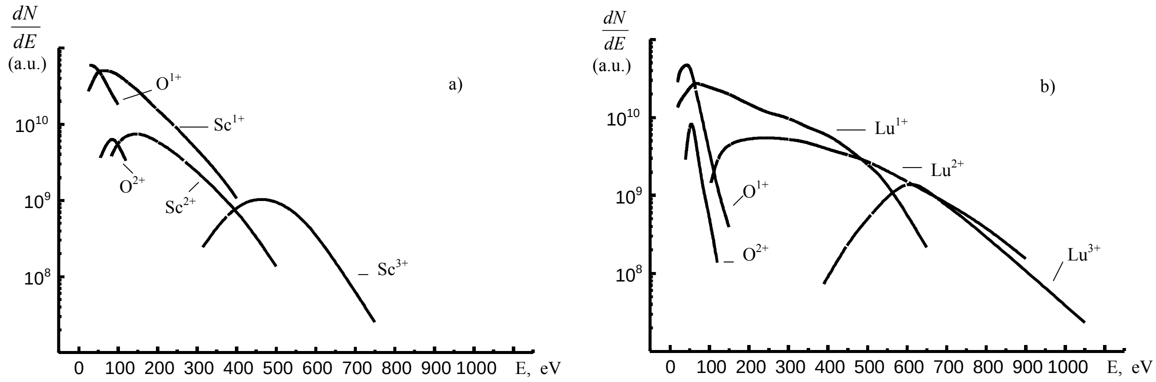

Fig. 1. Energy spectra of ions in two element Sc_2O_3 (a) and Lu_2O_3 (b) plasma, obtained at q=10^{11} W/cm^2.

the maximal energy increases more than two times (dashed curve in Fig. 2 (a)) due to the energy exchange between the ions of different mass. However, with further increasing the mass of the second component (dotted curve) the energy spectrum of O^{1+} ions again decreases. This nonlinearity indicates to the complex processes taking place in the highly charged plasmas. The energy spectra of O^{2+} ions for different mass of the second component of the target are shown in Fig. 2 (b). O^{2+} ions are mostly located in the interval of the energy between 40 eV and 120 eV and the energy range of the ions in this case does not strongly depend on the target composition. However, the number of ions per energy unit (*dN/dE*) is affected by the mass of the second component of the target. The latter again show the nonlinear behavior.

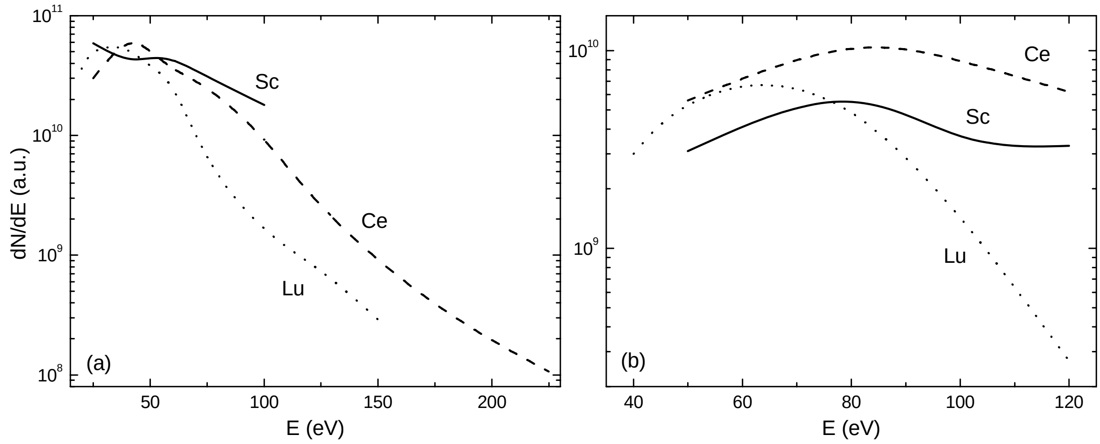

Fig. 2. Typical energy spectra of O^{1+} (a) and O^{2+} (b) ions in two element Sc_2O_3, Ce_2O_3 and Lu_2O_3 plasma.

We have performed our experiment for large number target composition in order to investigate the effect of the interaction between ions of different mass on the plasma formation process. Fig. 3 shows the maximal (a) and minimal (b) energies of O^{1+} (solid curves) and O^{2+} (dashed curves) ions as a function of the mass of the second component of the target. It is seen from this figure that the maximal energy of oxygen ions for both charge multiplicity first increases with increasing the mass of the heavy component of the target *m*. With further increasing *m* the energy decreases and start saturate after *m*>160 amu. The minimum energy of O ions does not show strong dependence on *m,* with a small decrease at larger mass of the atoms (see Fig. 3 (b)).

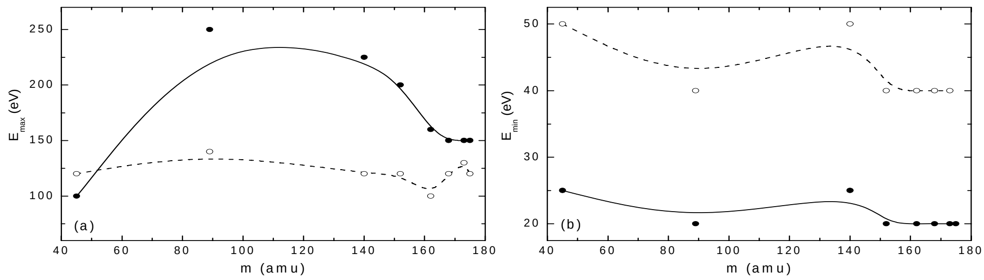

Fig.3. Dependence of maximal E_{max} (a) and minimal E_{min} (b) energies of O^{1+} (solid lines) and O^{2+} (dashed lines) ions on the mass of the second component of the plasma.

Comparative study of O ions and Sc (Ce, Lu) ions shows that the process of formation and expansion of O ions of all charge multiplicity is determined by the composition of the target. We notice that the heavy elements of the targets used in the experiment (Sc, Ce and Lu) have similar thermo-physical parameters, e.g. conductivity, meting temperature, thermal capacity, ionization potential. However, these elements differ with the mass and it is much lager than the mass of oxygen (mass of Sc, Ce and Lu atoms are 3, 9 and 11 times larger than the mass of oxygen atoms). This difference in mass plays considerable role in the formation of two-element plasma, and consequently to the energy exchange between the ions. Due to the lack of the experimental results for pure Sc, Ce and Lu targets, it is difficult to conclude about the effect of the oxygen ions to the properties of the ions of the second component of the target.

Conclusions

Using the mass-spectrometric method we studied mass-charge and energy spectra of two-element laser produced plasma ions generated from the surface of solid targets consisting of oxygen atoms and atoms of rear-earth materials. We found out that the maximum charge of plasma ions does not depend on the nature of the target for a given intensity of the laser radiation. The energy spectra of plasma ions consist of two packages of ions located in different energy ranges. Oxygen ions with charge Z=1,2 are located in low energy part of the spectra, while the second component of the plasma has larger energy diapason. We also found that the formation of mass-charge and energy spectra of multi-charge ions in two component plasma are described not only by the ionization and recombination processes, but also by the mutual interaction between the ions of different mass. For example, the maximal charge of the O ions increase with increasing the mass of the heavy component of the target for certain value of the mass and decreases with further increasing *m*; total number of doubly charged O^{2+} ions decreses with increasing the *m*, while O^{1+} ions have nonlinear dependence on the mass of the second component of the plasma.

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