*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-4.034 (2004)*

Ion emission from plasmas produced by a 438-nm laser radiation focused on targets of different Z-numbers

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1. Introduction

Hot and very dense plasma produced by a high power laser emits highly charged ions stream depending on the experimental conditions (e.g. [1-6]). The main factors influencing the nature of laser-plasma interaction are the laser and target parameters as well as the focusing conditions. Among others, the mechanisms of ion production and acceleration depend on a Z number of the target material. Properties of laser produced streams of ions of different elements were analysed in the far expansion zone in an experiment performed with the use of a high energy 3rd harmonic iodine laser beam of the PALS laser system at the PALS Research Centre ASCR in Prague (λ_L = 438 nm, E_L up to 250 J, $\tau_L \sim$ 400 ps). The properties of highly charged ion streams were investigated with the use of precision ion diagnostics based on the time-of-flight method. Attention was paid to the determination and comparison of the main ion stream parameters as well as to the ion acceleration processes occurring in plasmas of different Z-numbers.

2. Experimental arrangement and results

The investigations presented in this paper were performed using experimental systems at the PALS Research Centre in Prague. As a driver the iodine laser PALS [7] operating at the wavelength of 438 nm (3rd harmonic) 0.4-ns laser pulses have energy up to 250 J. The laser beam was focused on the planar targets (polyethylene-PE, Cu, Ag and Ta) by means of an aspherical lens at an angle of 30º with respect to the target normal. The maximum laser power density was 10^{16} W/cm^2 (at minimum focus spot of about 70 μm). The ion fluxes were analysed with the use of the ion collectors [3,5,8] placed at different angles with respect to the target normal at different distances of from the target. An ion energy analyser (IEA) gives the possibility of identifying the ion species produced, i.e. of determining their mass-to-charge ratios, energies and abundance. The IEA was placed far from the target perpendicularly to the target surface at distance of 2.5 m. The craters in the irradiated targets were investigated using a scanning electron microscope and a profiler with lateral and depth sensitivities of 1 nm. The experimental set-up is shown in Fig. 1.

The ion collectors recorded the existence of fast, thermal and slow ions (Fig. 2). Their characteristics correspond to the different mechanisms of ion acceleration and depend on a target Z-number at fixed experimental conditions. The group of faster nonthermal ions in the collector signal, if analysed by the IEA, is found to be composed of the high charge state of ions. The ions slower than thermal ions were emitted from cooler plasma produced by X-rays generated in the hot laser-heated plasma. The IEA spectra of ions of various Z-numbers differ significantly, as shown in Fig. 3. The spectra of heavy ions demonstrate clearly separated fast and thermal ion groups. The average velocities of fast ions of C, Cu, Ag and Ta generated by a high laser pulse energy at fixed experimental conditions were similar, at $E_L = 220 \pm 15$ J the average velocity of fast ions of different elements was $(1.2 \pm 0.2) \times 10^8$ cm/s. An increase of average fast ion energy with the increase of Z-number of the target material, shown in Fig. 4, is due to the increase of ion mass. A mass of material removed from the irradiated targets as a function of the laser pulse energy was calculated on the basis of the crater volume measurements. Results of these calculations are reported in Fig. 5. The ablation rate is of an order of 0.1 - 1 mg/shot, increasing roughly linearly with the increasing laser pulse energy. These yields correspond to $\sim 3 \times 10^{18}$ atoms for Cu and Ag and $\sim 6 \times 10^{17}$ atoms for Ta.

3. Discussion

The reported investigations have confirmed that a laser pulse of energy up to 250 J at wavelength of 438 nm, which heats the plasma of different Z-number, is capable of producing high-energy highly-charged ions, similarly as in our previous experiments [3,5].

It is believed that in the case of the short-wavelength laser-plasma interactions besides possible thermal ambipolar acceleration of ions anomalous phenomena occurring in the plasmas produced by the long-wavelength lasers (e.g. parametric instabilities, resonant absorption, ion-acoustic turbulence), nonlinear force effects including ponderomotive and relativistic self-focusing [1,9], which lead to very high laser intensities in a self-focused channel, may contribute to or even be the main reason for the appearance of high kinetic energy, highly charged ions. The similar average velocities of fast ions of different elements and different average charges indicate that ambipolar effect is not most important ion acceleration mechanism at the described experiment.

The different etching yields demonstrated for Cu, Ag and Ta targets (Fig. 5) can be explained on the basis of their different physical properties (e.g. melting and boiling points, heat of evaporation and specific heat).

This work was partially supported by International Atomic Energy Agency in Vienna under Contract No 11535/R0, the EU (project PALS/005) within the Contract No HPRI-CT-1999-00053), by the Grant Agency of the ASCR (Grant IAA 1010405), by the Ministry of Education of the Czech Republic (Project LN00A100), and by the 5th National Committee of INFN (ECLISSE and PLAIA Projects). The PALS laser operation was supported in part by the CAS grant No. K2043105.

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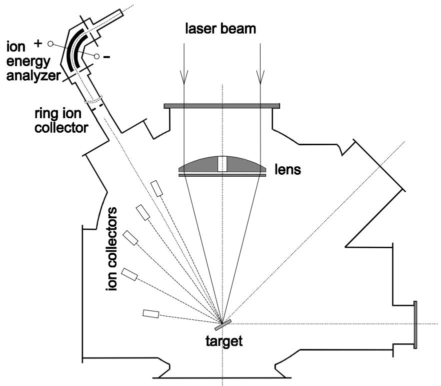

Fig. 1. Experimental set-up.

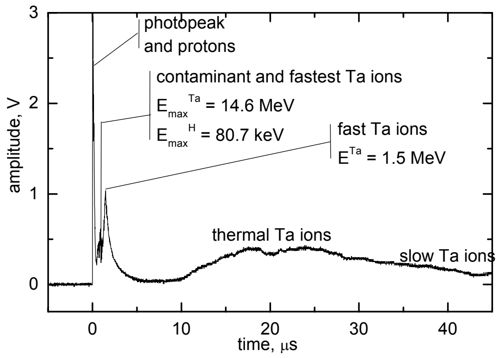

Fig. 2. Typical ion collector signal showing different groups of Ta ions.

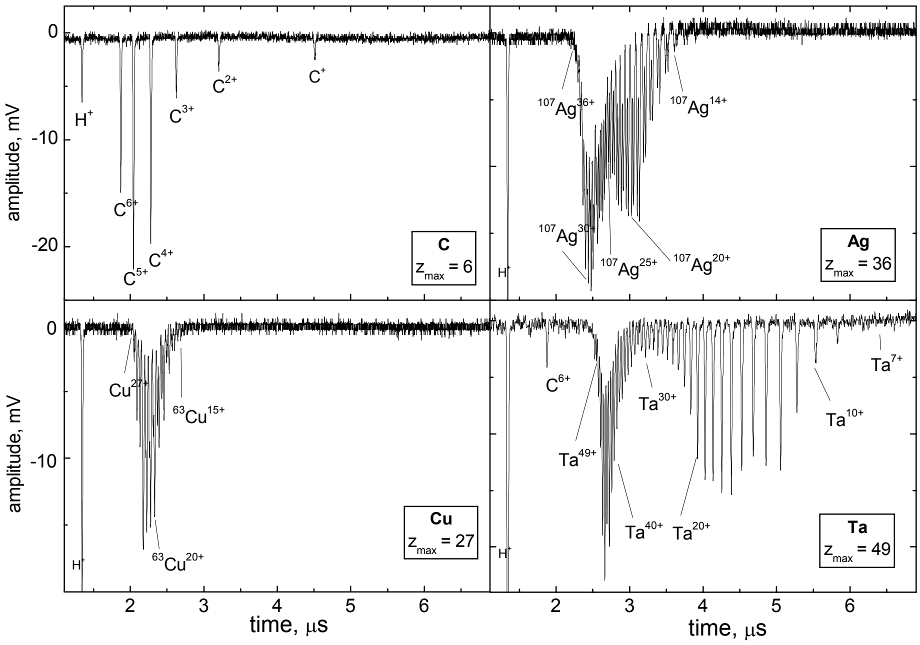

Fig. 3. Spectra of PE, Cu, Ag and Ta ions recorded at similar conditions.

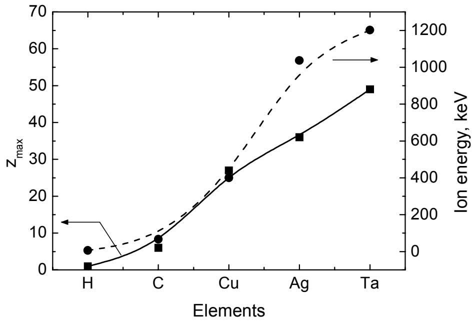

Fig. 4. Dependences of mean ion energy and z_{max} on a target Z number.

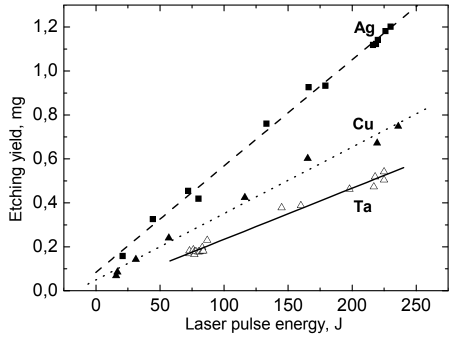

Fig. 5. Dependences of ablated mass on a laser pulse energy.