TPS ANALYSIS OF HEAVY-ELEMENT IONS FROM LASER-PRODUCED PLASMA[*]

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Abstract

The Thomson parabola spectrograph (TPS) is an excellent device to give a general overview of the charge states and the velocity (energy) distribution of all the types of ions produced by a single laser shot focused onto a target. Using the TPS and other diagnostics based on the time-of-flight method - ion collectors (IC) and a cylindrical electrostatic ion energy analyzer (IEA) – the laser produced plasma of different heavy elements was analyzed in a far expansion zone. As target material Ta, W, Pt, Au, Pb and Bi were chosen. The photodissociation iodine laser system PERUN was used for this purpose and results are compared with experiments obtained with the CO_2 laser ion source.

1 INTRODUCTION

The results of experiments on laser ion sources (LIS) performed up to now proved the feasibility of laser-production of highly-charged ions of heavy elements [1-4]. Current densities of multiply charged ions are about two orders of magnitude higher than those from the ECR ion source. This fact has lead to the construction of a LIS which may become a source for LHC. Nevertheless, the LIS still faces major technological problems as for applications of that kind.

TPS measurements [5,6] made it possible to analyze very effectively ions emitted from the target of different elements and also of ions in extracted ion beam [7]. A more detailed analysis of expanded ions was performed using a time-of-flight method.

In the presented contribution results obtained up to date with the photodissociation iodine laser at Prague are summarized and compared with those obtained with the CO_2 laser ion sources [1,3]. In addition, both the mentioned lasers are discussed with respect to their use for a considered LIS.

2 EXPERIMENT

The photodissociation iodine laser PERUN at Prague is operating at $\lambda = 1.315\ \mu m$, with the energy up to 40 J and with the pulse-length of 300-500 ps. Focusing the laser beam with either lens optics or with a parabolic mirror to a spot size of about 100 μm means attainable power density on the target up to about $1\times10^{15}\ W/cm^2$ (reduced intensity $I\lambda^2 = 1.7\times10^{15}\ W\mu m^2/cm^2$).

The operation principle of the TPS is based on the passage of ions through parallel magnetic and electric fields, ***B*** and ***E***. From the solution of equations of motion for a charged particle we obtain the coordinates x and y of the point in the recording plane of a plane detector (a MCP in our case), onto which an ion of given parameters impacts. After eliminating the kinetic energy of ions E_i we obtain an equation, which describes the Thomson parabolas [5,6]. Points of intersection of parabolas with a straight line passing through the origin of coordinates, Oxy, correspond to ions of a fixed velocity v_i. To overcome difficulties with the identification of highly charged ions, to make the evaluation of parabolas easier and to help further data processing, the computer program THOMSON was developed [6,8].

Two types of ion collectors (IC) - a flat one and a ring (coaxial) one, which allows to measure the ion current close to the TPS or IEA axis - were used for a registration of the time-resolved ion current signal, from which the ion current densities can be derived. The humps on a collector signal usually indicate several ion groups which may be ascribed to different mechanisms of their production [2]. We also used a cylindrical electrostatic ion energy analyzer (IEA) for a separation of ions with different ratio of mass to charge state M_i /z to determine the relative abundance of ions produced. Experimental arrangement as well as the ion diagnostic tools are described, in a more detail, elsewhere [9,10].

The results obtained with the iodine laser used are summarized in the Table 1 (with exception of Ta for not fully optimized conditions). Paths of flight of ions ranged from 84 cm to 187 cm. The average total current densities

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j_{th} and j_f are the peak values of the fast and thermal ion signals, recalculated to the distance of 100 cm according to a L^{-3} law, the widths (FWHM) of corresponding signals Δt_{th} and Δt_f are usually about 2 μs and 0.7 μs, respectively, or lower. Results for Ta and Pb ions produced by CO_2 laser [1,3] are included in this Table, too, for a comparison (Δt_{th} is about 5 μs in this case).

From the values of j_f, j_{th}, Δt_f and Δt_{th} the number (fluency) of considered ions can be estimated, if the relative abundance of ions in the group is known. Such estimations give for iodine laser produced Ta^{40+}ions the value of about 1×10^8 ions/cm^2, for Ta^{20+} values about 6 times higher.

3 DISCUSSION

Table 1 shows that the short-wavelength and short-pulse iodine laser achieves much higher charge-states than the CO_2 laser and that the group of fast ions is missing in the second case. The ions are generated by an intense collisional ionization in the hot core of plasma, formed by a short intense laser pulse. Owing to a long wavelength of a CO_2 laser the critical density is low (about 65 times in comparison to that for iodine laser) and the ionization is slow. In the case of iodine laser the estimated electron temperature of plasma exceeded 1.5 keV, while in the case of CO_2 laser it is only about 400 eV [11].

The higher power density, the higher plasma temperature is and the higher charge states are produced [9,12]. Losses of the charge suffered by ions emitted from a laser plasma were studied recently for Ag, Cu, Ta and Pb using the iodine laser. Two ion collectors (a ring one and a flat one) were used to measure simultaneously ion current in the same direction and at two distances from the target (from 84 cm to 187 cm). It was confirmed that the decrease in the total charge carried by ions obeys nearly a L^{-2} law, as it is generally accepted, independently of the amount of transferred charge [13]. It means that recombination of ions does not proceeds at these distances and high charge states are really “frozen”. Different situation is valid for the CO_2 laser. According to calculations of Roudskoy [11] the critical distance L_{cr} from the irradiated target, where the sharp rise of the recombination losses changes to a slow descend, may reach a few meters. The TPS, when installed at CERN, gave evidence for ion recombination not only in freely expanding plasma, but pictures of recombined ions were registered also after an extraction of Ta ion beam from the plasma [7].

4 CONCLUSIONS

From the experiments performed up to now it is possible to conclude:

a) Lasers with a shorter wave-length and shorter pulse-lengths can produce ions with higher charge-states much more easily than CO_2 laser.
b) Ions of heavy elements with charge states up to about 50+, and current densities above 10 mA/cm^2 at the distance of 1 m may be achieved with iodine laser at power densities of 1×10^{15} W/cm^2.
c) The occurrence of the highest charge states in the far expansion zone is ascribed to the presence of a fast ion group (fast electrons) [2].
d) Practical reasons (high energy at 1Hz repetition rate with 10^6 shots now achievable for an acceptable amount of money) dictated the use of the CO_2 laser as the first choice for a driver at CERN, considered as an alternative ion source for LHC [14]. Iodine, but more probably Nd lasers are predestined for a LIS of the next generation (smaller size, more progressive solution - one level of stripping might become superfluous, at least).
e) TPS seems to be a very good device for checking the LIS operation.

Table 1: Main parameters of laser produced ions of heavy elements.

	iodine laser						CO_2 laser	
	Ta	W	Pt	Au	Pb	Bi	Ta	Pb
z_{max}	55	49	50	51	51	51	25	35
$<z_f>$	42	45	40	38	40	40		
$<z_{th}>$	35						20	30
$E_{i,max}$, MeV	8.8	4.9	8.5	4.8	5.1	5.1	0.5	0.5
$<E_{i,f}>$, MeV	3.4	2.4	3.1	3.1	3.3	2.7		
$<E_{i,f}>/A$, keV/u	18.7	13.1	15.9	15.7	15.9	12.9		
$<E_{i,th}>$, keV	700						58	100
$<E_{i,th}>/A$, keV/u	3.9						0.32	0.48
j_f , mA/cm^2	17.4	8.6	11.5	11.0	6.6	8.6		
j_{th} , mA/cm^2	35.3	12.1	10.1	21.9	11.1	13.0	8.5	40.5

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