*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-4.013 (2002)*

Angular distributions of ions emitted from the laser-produced plasma in a magnetic field

J. Wołowski, J. Badziak, I. Ivanova-Stanik, P. Parys, W. Stępniewski and E. Woryna,
Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland

1. INTRODUCTION

Investigations of angular distributions of ion emission from the laser-produced plasma make it possible to explain some aspects of physical processes taking place in the laser-produced plasma and they are also stimulated by a necessity of optimisation of a laser ion source (LIS) for particular applications. The laser-produced plasma was proposed and proved to be an efficient source of ions, which can be used for different applications (e.g. for particle accelerators, an ion implantation technology [1-4]). External magnetic and electric fields may modify the characteristics of the laser produced ion beams according to specific technological demands. The studies described here have been carried out at the IPPLM in Warsaw, in order to show the effect of an axial magnetic field of induction within the range of 0.2 – 1.2 T on the parameters of the tungsten ion beam extracted from the plasma produced with the use of 1-ns Nd:glass laser pulse of energy 0.1-2 J at the power densities 10^{10} - 10^{11} W/cm^2. Simple Monte–Carlo simulations of the properties of a laser generated ion stream expanding freely and in the presence of magnetic field were carried out and compared with the experimental results. Our studies were also motivated by the possible applications of LIS as an ion source for a hybrid ion source consisting of the LIS coupled to the ECRIS (Electron Cyclotron Resonance Ion Source), funded by INFH LNS in Catania (Italy) and investigated in Catania and at the IPPLM in Warsaw [5,6].

2. APPARATUS AND METHODS

The investigations were performed at the IPPLM in Warsaw by using a Nd:glass laser operated at the wavelength of 1.06 μm and the output energy up to 2 J in the 1 ns pulse. The laser beam was focused onto a spot of diameter of ~1.5 mm by means of an aspherical lens (f = 411.6 cm) perpendicularly to the target surface. A cleaned massive W target was located at the distance of 338 cm from the focusing lens (the laser focus was behind the target surface). The Helmholtz coils generating a nearly homogenous magnetic field at induction in the range 0.2 - 1.2 T were located in front of the target. The ion diagnostics for measuring the ion stream parameters (see Fig. 1), i.e. ion collectors, ICs, and an electrostatic cylindrical ion-energy analyzer, IEA, are based on the time-of-fight method [7]. For measurements of angular dependences of ion stream parameters, i.e. means: the charge carried by ions, the ion current density and the ion velocity distribution a set of 3 small ion collectors (IC1-IC3) was located at distances of 74.6 cm from the target at angles: 2,3°, 4,7° and 7° to the target normal, respectively. Additionally, two collectors (IC4 and IC5) were placed at distances of 68.8 cm and 48.6 cm, respectively and at angles of 10.7° and 19.2°, respectively. The IEA was placed at a distance of 195.2 cm from the target at about 6° to the target normal.

The ICs deliver a charge integrated and time-resolved signals of ion current from which the total charge, mean and total energy carried by ions, as well as ion velocity (energy) distribution can be delivered [7,8]. The IC signal if combined with the record of IEA ion spectra, enables a determination of energy distributions and abundance of particular ion species as well as ion energy distributions for all ion species, the average charge state of ions, a total number of ions and energy carried by them.

3. RESULTS AND DISCUSSION

Ion collector signals usually show the occurrence of at least two groups of ions, the existence of which corresponds to different kind of ions reaching the IC. The first (faster) ion group of the collector signal contains mostly ions of light contaminants (mainly H, C and O), while the second (slower) ion group contains W ions only, similarly to what was demonstrated in our previous experiments [6,9]. A number of shots onto the same place on the target surface does not essentially change the collector signal with an exception of the first ("cleaning") laser shot producing a large amount of light ions. Fig. 2 shows examples of ion collector signals and IEA spectra recorded for freely expanding plasma and for plasma expanding in the magnetic field at induction of 1.2 T. The W ions recorded by the IEA contain of 83 % of W^{+} with energy in the range of 0.1–2.6 keV, 16.5 % of W^{2+} with energy in the range 0.8–2.8 keV, and 0.5% of W^{3+} with energy in the range of 1.2–3.6 keV. At B = 1.2 T the maximum charge recorded with the IEA was also $z_{max} = 3$ with energy of about 1.1 keV. Fig. 3 shows examples of the angular distributions of maximum current density of W ions, $j_{W,max}$, at two incident laser energies, ~0.09 J and ~1.2 J for B = 0 and B = 1.2 T. It is seen that the distributions are strongly peaked in normal direction to the target surface and can be roughly fit by $j_{W,max} \propto \cos^{x}\alpha$-dependence. The scaling lows of

$j_{W,max}$ for B = 0 and B = 1.2 T are given in Fig. 4. From this figure it follows, that $j_{W,max}$ is an increasing function of the laser pulse energy, E_L, in both cases while the x-exponent increases for B = 0 and slightly decreases for B = 1.2 T with an increase of the E_L. The maximum ion current density of W ions at B = 1.2 T is more than a twice high than at B = 0 in the whole laser pulse energy range.

Examples of the ion velocity distributions for freely expanding plasma and for plasma expanding in the magnetic field with induction of B = 1.2 T calculated on the basis of IC1 ad IC4 collector signals are shown in Fig. 5. The distributions of ion velocities for expanding in the magnetic field are narrower than in the case of B = 0 (the maximum ion velocity is evidently higher at B = 1.2 T then for the one at B = 0). To obtain the velocity distributions of W ions a separation of contaminant ions from W ions was made for IC signals by fitting proper functions for the ion collector signals is needed (Fig. 5).

The Monte Carlo Code was used to find out how magnetic field can changed angular and velocity distributions measured in our experiment. As initial conditions shifted, Maxwell distribution of ion velocity and expansion velocity equal to $v \approx 3 \cdot 10^6$ cm/s were taken. According to the experimental result the angular distribution of ion emission was characterised by the dependence $\cos^x\alpha$.. For this simple case it is possible to use an analytical solution for equation of motion. From the computed ion velocity distributions for IC4 (Fig. 6) one can see that a magnetic field reduces a number of ions recorded at higher angles. This effect is in a qualitative agreement with the experimental results.

Acknowledgements: This work was partially supported by the grant No 5 P03B 108 20 of the Polish Committee for Scientific Research.

References

[1] H. Haseroth, H. Hora in "Adv. of Accel. Phys. and Techn." (World Sci.),1993, p. 4463
[2] L. Láska et al., Rev. Sci. Insrum. **69** (1998) 1072
[3] F. P. Boody et al., Proc. of 13th Inter. Conf. LIRPP Monterey, USA, 1997, p.539
[4] S. Gammino et al., Rev. Sci. Insrum. **71** (2000) 631
[5] S. Gammino et al., Rev. Sci. Insrum. **73** (2000) 650
[6] J. Wołowski et al., Laser and Part Beams **20** (2002) in print
[7] E. Woryna et al., J. Tech . Phys., **XLI** (2000) 521
[8] E. Woryna, P. Parys, J. Wołowski and W. Mróz, Laser and Part Beams **14** (1996) 293
[9] J. Wołowski et al., Optica. Applicata **XXX** (2000) 69.

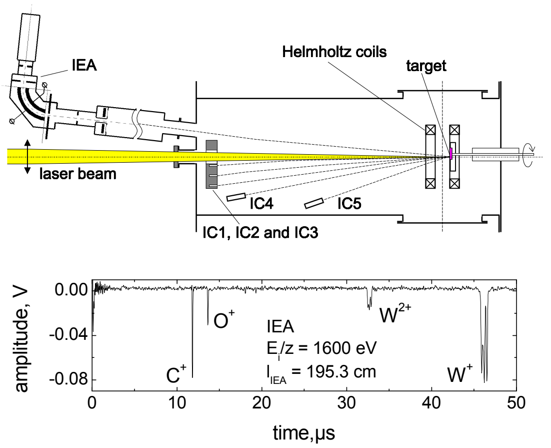

Fig. 1. Experimental arrangement (top) and an example of IEA spectrum (bottom) for B = 0 and E_L = 1.2 J.

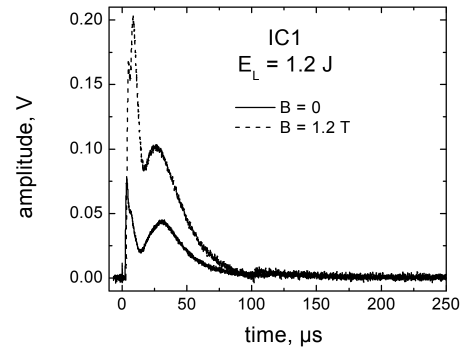

Fig. 2. IC1 ion collector signals of W plasma (E_L ~1.2 J for B = 0 and B = 1.2 T).

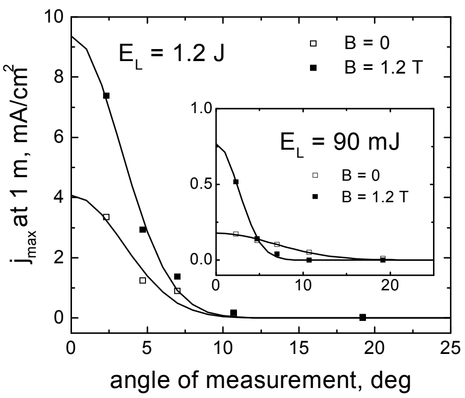

Fig. 3. Angular distributions of the maximum current density of W ion group (E_L = ~0.09 J and ~ 1.2 J for B = 0 and B = 1.2 T).

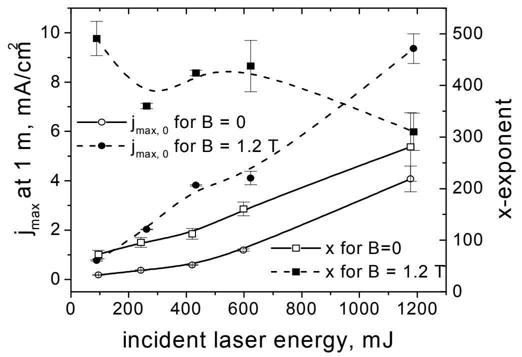

Fig. 5. The maximum in current density and x-exponent of the dependence $j_{W,max} \propto \cos^x\alpha$. as a function of the laser pulse energy for B = 0 and B = 1.2 T.

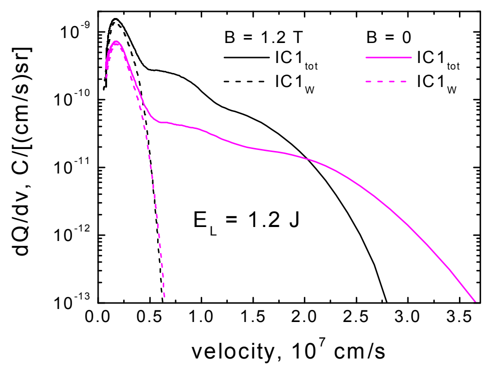

Fig. 4. Velocity distributions of a total ion stream and stream of W ions recorded by IC1 (E_L ~1.2 J for B = 0 and B = 1.2 T).

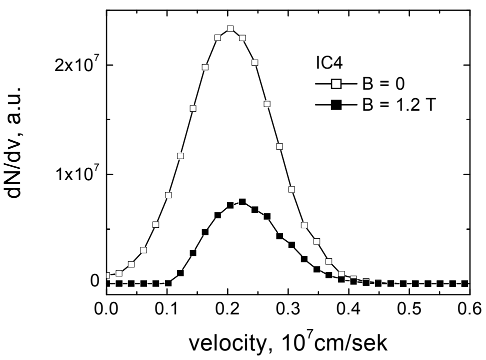

Fig. 6 An example of computed velocity distributions of W ions reaching the IC4 for B = 0 and B = 1.2 T.