

PRODUCTION OF SLOW ION BEAMS FROM A LASER ION SOURCE

S. Gammino, G. Ciavola, L. Torrisi, L. Andò, L. Celona, INFN-LNS, Catania, Italy
L. Laska, J. Krasa, IP ASCR, Prague, Czech Republic
J. Wolowski, E. Woryna, P. Parys, IPPLM, Warsaw, Poland
G. D. Shirkov, JINR/LPP, Dubna, Russia

Abstract

At the Laboratori Nazionali del Sud (LNS) we have designed a hybrid ion source, consisting of a Laser Ion Source (LIS) as first stage, which gives intense currents of electrons and of multiply charged ions ($q/m=1/10$ or lower), followed by an ECR ion source as a second stage, which acts as a charge state multiplier. Preliminary experiments for the ECLISSE experiment (Ecr ion source Coupled to a Laser Ion Source for charge State Enhancement) have been carried out at IPPLM in Warsaw, in order to show the beneficial effects of the magnetic axial field on the extraction of the ions from the Laser Ion Source.

In addition, at LNS we have been looking for a regime of the LIS which minimizes the beam energy which is a crucial parameter for the coupling to the ECR plasma. The best results obtained up to date range between 100 and 1000 eV for Al, Ni, Ta beams with charge states up to 5. The description of the tests and the perspectives of the experiment will be reported.

1 INTRODUCTION

The idea of a new type of ion source (hybrid ion source) was introduced at LNS two years ago [1]. It consists of a Laser Ion Source as the first stage followed by an Electron Cyclotron Resonance ion source as the second stage.

The preliminary tests have been carried out at IPPLM in order to show the effect of a solenoidal magnetic field and of a bias voltage on the extraction of ions from the LIS and the results are reported in [2]. The next tests concerned the ion beam energy minimization, which is a crucial parameter for the coupling of the LIS to the ECRIS. On the basis of calculations [3] it was estimated that energies of the order of some hundreds of eV or lower allow an efficient coupling of ions to the ECR plasma.

The experiment which were carried out with the LIS of LNS demonstrated the feasibility of the production of low energy, low charge states ion beams which were obtained for some metallic samples with remarkable intensities.

2 THE EXPERIMENTAL FACILITY

The following experimental facility was realized as in fig.1: the target chamber is provided with an input window (40 mm in diameter) for laser beam, of two output windows ($\phi=40$ mm) for ion measurements (one at 45° , the other perpendicular to the laser beam), of one window for Quadrupole Mass Analyzer ($\phi=145$ mm) and of a window for target manipulation or for diagnostics ($\phi=145$ mm).

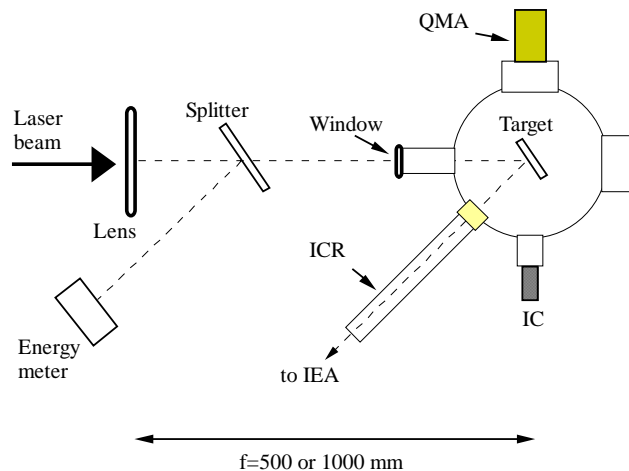


Figure 1: The scheme of the experimental setup (upper view).

The target holder was mounted from the bottom. Its angular position was fixed (45° with respect to the laser beam), but with the possibility of vertical movement (about 80 mm), so that the different metallic samples could be mounted at the same time and their replacement could be carried out without breaking the vacuum. The test chamber was pumped by a 300 l/s turbomolecular pump and typical vacuum was about 1×10^{-7} mbar.

The optical system consisted of the Nd:YAG laser, of the He-Ne laser for alignment, of 2 beam splitters and 2 diaphragms (12 mm in diameter) and of 2 focusing lens ($f=1000$ mm or $f=500$ mm).

A photodiode and a calorimeter with laser energy monitor were used for laser diagnostics. The Nd:YAG laser main nominal parameters were 0.9 J - 9 ns, repetition rate up to 30 Hz, divergence of the beam below 1 mrad.

Minimum spot diameter was estimated to be 0.5 mm at the distance of 55 cm, which means that the highest attainable laser power density was lower than 5×10^{10} W/cm². The maximum power density that can be achieved with this setup may be three times higher, by operating the laser with the short pulse option (2.5 ns instead of 9 ns) but we did not perform such a measurement because we expected that higher ion energies are generated in that case, according to literature [4].

Three different ion collectors and cylindrical electrostatic ion energy analyzer (IEA) [5,6] were used during experiments, together with the Quadrupole Mass Analyzer, which served mainly for the registration of the gas composition in the target chamber during experiment.

The path lengths from the target to the Ion Collector ranged from 22.1 to 31.6 cm.

Ring ion collector (ICR) made the measurement of ions close to the axis simultaneously with the IEA possible (fig. 1). A windowless electron multiplier was used for ion measurements. Fig. 2 shows a typical ion collector signal, with two peaks corresponding to light ions and to Tantalum ions respectively.

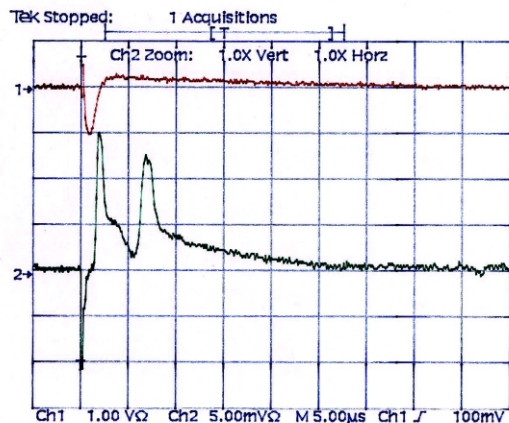


Fig. 2: A typical ion collector signal (lower trace) compared to the photodiode signal (upper trace).

3 THE EXPERIMENTAL RESULTS

Properties of ion beams from laser produced Al, Ni and Ta plasmas, i.e. the average ion energy $\langle E \rangle$ and ion current I , were evaluated from ion collector signals for different values of laser energy E_L and for two focusing lens ($f = 500$ mm or $f = 1000$ mm); different lens positions (LP) with regard to the target were also tested.

It was observed a non linear dependence of $\langle v \rangle$, $\langle E \rangle$, and I on laser energy E_L because the laser divergence changes with the increasing E_L . By changing the lens or divergence of the laser beam (due to the change of laser

energy or due to long time instability), the diameter of minimum focal spot is changed, too, according to the relation $r = f \Theta$ (where r is the radius of the focused beam, f is the lens focal length, Θ is the laser beam divergence). For the power density I_L [W/cm²] the following relation is valid: $I_L = W / \pi r^2 = W / \pi f^2 \Theta^2$ (W is the laser power).

The results for different metals are summarized in Figs. 3,4. There is a maximum which confirms the above mentioned shifts of the minimum laser spots, showing that j_{\max} and $\langle E \rangle$ do not depend on the laser energy but rather on the laser power density I_L .

Anyway, what is more important for the ECLISSE experiment, the mean ion energy is much higher by using of a lens with $f=500$ mm because the laser power density is much higher in such case. In the hybrid ion source, the focal length will be higher, then the useful power density will be just above the threshold. It is worth comparing the threshold energies for laser ion production in both cases, which is about 100 mJ for $f = 500$ mm lens and about 300 to 400 mJ for 1000 mm lens (it has been observed that similar results occur for neutrals [7]). In agreement with this result, fig. 4 shows that j_{\max} exhibits a maximum at $E=700$ mJ as it was for energy in fig. 3. The ion current I depends both on the ion charge states and on the number of ions, i.e. on the temperature and on the volume of the plasma, from which ions are emitted.

Finally the dependence of the ion production on the laser power density is non-linear as it was shown in [4]. Clearly this aspect deserves more investigation but we can conclude that there is a wide energy region (300-600 mJ for lens with $f = 1000$ mm and 100-200 mJ for $f=500$ mm), in which very low energy ions can be produced ($\langle E \rangle$ 0.2 to 0.5 keV), with values of j_{\max} in the order of 20 to 30 mA/cm². For higher power the ion current density may be substantially higher, but ions have mean ion energy $\langle E \rangle$ of few keV and the coupling efficiency should be lower.

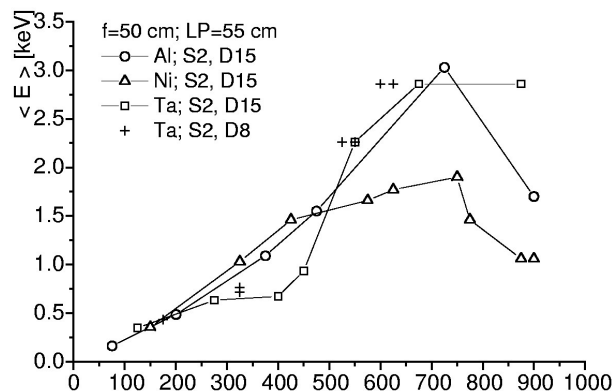


Fig.3: Mean ion energies, $\langle E \rangle$, of Al, Ni and Ta ions vs. the laser energy E_L for the same experimental conditions (lens with $f = 500$ mm, ion collector IC(S2), diaphragm 15 mm in diameter).

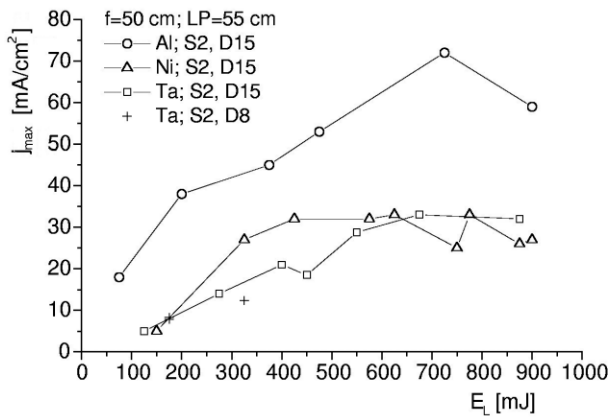


Fig. 4 - Maximum current densities of Al, Ni and Ta ions, j_{\max} , vs. the laser energy E_L .

In tab. 1 the measured values of ion velocity and energy and of ion currents are summarized. Maximum currents were twice for Al than for Ni and Ta, as it can be expected by simple considerations [7].

As for ion composition, the beams consist mainly of ions with charge states from 1+ to 4+ (the highest charge state detected by the IEA was 6+).

Tab. 1 – Summary of measured $\langle v \rangle$, $\langle E \rangle$, j_{\max} , for Al, Ni, Ta ions.

Ion	$\langle v \rangle$ [cm/s]	$\langle E \rangle$ [keV]	j_{\max} [mA/cm ²]
Al	$3 \times 10^6 - 1.5 \times 10^7$	0.25 - 3	145
Ni	$3 - 8 \times 10^6$	0.25 - 2	79
Ta	$1 - 6 \times 10^6$	0.1 - 3	65

Another interesting test consisted of applying repetitive regime of the laser (175 mJ, 30 Hz, 20 sec) without changing the target position; Ta ions were produced with energy decreasing with the number of shifts (from 0.8 to 0.4 keV) but average currents did not change too much, fluctuating above 20 mA/cm².

This result is not clearly understood, but it seems that after the first shots, the ion temperature and charge states are limited, therefore it is a regime which can be successfully used for long term stability. By using the same target position, almost stable currents of ions are extracted with a lower charge state, but (what is more interesting for us) also with a lower energy.

More tests were also carried out to determine the existence of a threshold below which no neutral component emission occurs [7]. Above the threshold, the ejected mass yield is about proportional to the energy of the laser irradiation. If the QMA yield (maximum height) is plotted as a function of the laser pulse energy, the results are fitted by a straight line [7]. Data indicate that the energy threshold depends on the type of metal. The experimental etching thresholds range between 0.05 J for lead and 0.75 J for gold. In terms of energy density the

minimum experimental value was measured in Pb while the maximum value of 1.58 J/cm² was found in W.

The experimental etching rates, measured weighting the samples before and after 1000 pulse irradiation at the energy of 875 mJ, range between 0.25 and 10.5 $\mu\text{g}/\text{pulse}$ for copper and lead, respectively.

4 NEXT TESTS AND PERSPECTIVES

The experiments carried out in 1999 and 2000 gave promising results as for the production of high current of low energy multiply charged ions by means of a Laser Ion Source. The experiment with high repetition rates confirmed the feasibility of the hybrid ion source [1]. Anyway, in order to be able to design and operate this source, much more exact and systematic studies have to be carried out, especially on the long term stability of the LIS under the conditions here described.

The success of the experiment here described consists of demonstrating the feasibility to operate the LIS in such a regime to produce low energy multiply charged ions [8].

The reproducibility of the results of the LIS when it was operated in such a regime can also be considered as an important starting point for future experiments.

Moreover, the know-how that we have obtained may be successfully used in other experiments. In fact, the ECLISSE ionization scheme may be used also for charge breeding of radioactive isotopes, by using the LIS as a selective source for 1⁺ ionization of recoils, to be efficiently produced as slow ions, in order to optimize the injection into an ECR ion source for N⁺ ionization.

ACKNOWLEDGEMENTS

The support of Mr. S. Marletta, E. Messina and F. Chines is gratefully acknowledged.

The financial support provided by the Fifth Committee of INFN is also acknowledged.

REFERENCES

- [1] S. Gammino et al., Proc of the 14th Workshop on ECR Ion Sources, Geneve, (1999), 98.
- [2] S. Gammino et al., Rev. Sci. Instrum. 71 (2000) 1119.
- [3] G.D. Shirkov et al., to be presented at the Conference on Highly Charged Ions (2000), Berkeley.
- [4] J. Krása et al, Proc. XXIV. Int. Conf. on Phenomena in Ionized Gases, Warsaw, 1999, ed. P. Pisarczyk, T. Pisarczyk, J. Wolowski, Vol. II, p.103.
- [5] E. Woryna et al., Laser Part. Beams 14 (1996) 293.
- [6] L. Láska et al., Rev. Sci. Instrum. 67 (1996) 950.
- [7] L. Torrissi et al., Rev. Sci. Instrum., accepted for publication.
- [8] J. Wolowski et al., Proc. of the European Conf. on Laser Interaction with Matter (ECLIM2000), to be published