THE ECLISSE PROJECT

S. Gammino, L. Andò, L. Celona, G. Ciavola, L. Torrisi, INFN-LNS, Catania, ITALY
J. Krasa, L. Laska, M. Pfeifer, K. Rohlena, IPASCR, Prague, CZECH REPUBLIC
B. Badziak, P. Parys, J. Wolowski, E. Woryna, IPPLM, Warsaw, POLAND;
G. Shirkov, JINR, Dubna, RUSSIA

Abstract

The ECLISSE project (ECR ion source Coupled to a Laser Ion Source for charge State Enhancement) started in 1999 with the aim to obtain intense beam of highly charged ions (pulsed mode) by means of the coupling between a Laser Ion Source (LIS) and an electron cyclotron resonance (ECR) ion source. The major points to be investigated appeared to be the coupling efficiency between the ion beam produced by the LIS and the ECR plasma, as well as the possibility to enhance the available charge state by an ECRIS with respect to the standard methods which are used to produce ion beams from solid samples (i.e. evaporation and sputtering). The calculations have confirmed that this concept may be effective, provided that the ion energy from the LIS is not higher than a few hundreds of eV. The main features of the calculations will be shown, along with the results obtained in the off-line test at LNS facility (Nd:YAG laser 0.9 J / 9 ns) and at IPPLM facility (Nd:glass laser 10 J / 1 ns). The hybrid ion source is described in the following and the programme of the final tests will be outlined.

1 INTRODUCTION

The hybrid source [1,2] will combine the advantage of a LIS (intense beam, availability of metallic ions) with the advantage of an ECRIS in terms of continuous beam, good emittance, stability and energy spread. We have studied in detail the main limitations to the efficient cooperation of the two ionisation methods and particularly we have measured and/or simulated the efficiency of the coupling process of ions from the LIS beam to the ECRIS plasma; the energy distribution and charge state distribution (CSD) produced by the LIS at different laser power density; the etching rates and the amount of the ionic and neutral components extracted from the target; the effect of the magnetic field on LIS output; the effect of biasing the metal target.

1.1 The coupling

The main requirement for multicharged ion loading is that the ions should be slowed down and trapped in the ECR plasma. By using the theory of elastic Coulomb collisions in the plasma, the ion beam absorption by the plasma of L length is estimated as follows

$$N_i = N_0 (1 - exp(-L/l)) \qquad (1)$$

where L is the length of the plasma volume along the ion beam axis, and l the mean free path of the beam ions in the plasma. For example, either for the chromium and gold ion, beam absorption in the oxygen plasma (density $n_e = 4\ 10^{12}$ cm^{-3}, $L_{plasma} = 12$ cm) is efficient provided that the ion energy per charge does not exceed a few hundreds of eV [3]. The coupling efficiency is close to zero for $E_i \geq 1$ keV, being E_i the energy per charge state i. It should be also considered that the ion beam which stops in the plasma transfers its kinetic energy to the plasma particles. If the total ion number in the beam is determined as $N_i = 6.2{\bullet}10^{18}\ I\ \tau_i$, then the total beam energy (eV) will be:

$$E = 6.2{\bullet}10^{18}\ I\ \tau_i\ i\ E_i \qquad (2)$$

where I is the current (A) and τ_i is the pulse duration (s). Beam ions interact mostly with the plasma ions and heat them. The initial total ion energy in the plasma of volume V and ion temperature T_i is

$$E_0 = T_i\ V\ n_e / k \qquad (3)$$

The energy transfer from the beam to the plasma should be lower to avoid that the beam perturbs the plasma. Fig. 1 shows the total beam energy E in terms of the energy per charge E_i (the two lines are corresponding to a beam current I=0.1 A and 0.3 A) in comparison with the total energy of ions E_0 in the plasma which parameters are: $k = 6$, $n_e = 4\ 10^{12}$ cm^{-3}, $V = 600$ cm^3, $T_i = 20$ eV. A current of 100 mA can be absorbed up to energies of 300 eV.

Calculations have been carried out for different metallic ions, and for the typical axial field profile of the SERSE superconducting ion source [4]. For sake of simplicity, the injection of a constant flux of 0.1 A burst, 20 µs long pulse of ions with an average charge state equal to 2 was assumed. It was also assumed that a pure oxygen plasma is created and stored during 100 ms up to the stable state with electron density of 4÷5 10^{12} cm^{-3}and total RF power of 1500÷2000 W before the laser injection.

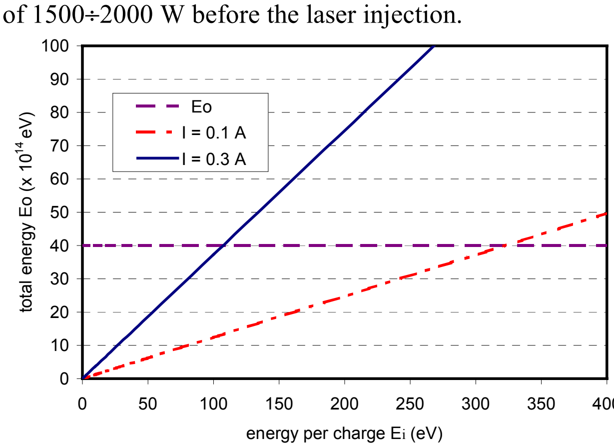

Figure 1: Comparison of the ion beam energy and of the the plasma ions energy content.

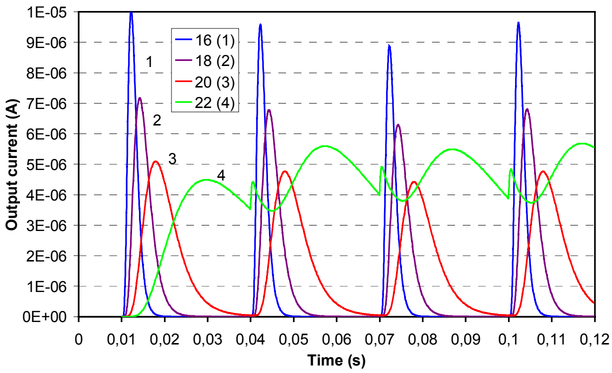

Figure 2: Cr high charge states buildup vs. time.

Fig. 2 presents the results of calculations for chromium ion production with external injection into the plasma.

It may be observed that we can choose an optimum charge state with the maximum output current by selecting the time for the given element and the plasma parameters. For the highest charge states a nearly dc beam can be obtained.

2 THE EXPERIMENTAL SET-UP

The LIS operating at INFN-LNS is based on a 30 Hz, 1064 nm Nd:Yag laser, with 9 ns pulse width and a maximum power density of about 10^{10} W/cm^2. The test bench is shown in fig. 3. The laser light is focused on metal targets with a spot size ranging between 1 mm^2 and 6 mm^2. In these tests, the irradiated targets were pure sheet of tantalum, 1 mm thick. An electrostatic deflection ion energy analyzer (IEA) is used along the normal to the target surface to detect the energy-to-charge ratio, E_i, as a function of the laser pulse energy and of the focusing position. By changing the plates bias, it is possible to select different ratios and to detect the transmitted ions by means of a windowless electron multiplier (WEM). The IEA is employed for time-of-flight (TOF) measurements with a target-WEM distance of 1.5 m. More details on the experimental apparatus are report in literature [5].


Figure 3 : The experimental setup at INFN-LNS.

3 LASER ION SOURCE (LIS) TESTS

The laser interaction with metallic surface produces either etching, neutral emission and ion emission above a well defined threshold.

At LNS we have demonstrated that the experimental thresholds for the ion emission is very close to the threshold for the neutral emission [6].

The atomic neutral emission was monitored by a mass quadrupole spectrometer and by the vapor thin film deposition technique. The energy thresholds, the emission yields, the angular distribution, the fractional ionization, the kinetics and characteristics of the plasma production and the ion charge state have been studied for Al, Ti, Ni, Cu, Nb, Sn, Ta, W, Au and Pb targets [6,7]. Another interesting aspect concerns the yield of the ion emission from the irradiated tantalum target. This yield is of the order of 0.8 µg/pulse at 10^{10} W/cm^2, corresponding to an atom emission of 2.6×10^{15}/pulse. However, in this case only about the 20% of the emission is ionised while at higher power density a higher fractional ionisation occurs [8]. If we compare the corresponding flow of neutrals from sputtering system and oven used to provide metal atoms to ECRIS plasma, it is evident that the yield is much higher in the case of the LIS, so that much higher currents may be expected by the ECRIS itself. Anyway the ion component should obey to the limitations in §1, then the laser energy cannot exceed few hundreds of mJ and the useful charge states are low. Fig. 4 shows a typical IEA spectra corresponding to the tantalum irradiation at 150 mJ, featuring only five charge states. At 500 mJ laser pulse the maximum charge state increases to 8^+ [8].

3.1 The influence of electric and magnetic fields

The ion velocity distributions of W plasma expanding in presence of magnetic and electric fields have been compared to the case of freely expanding plasma [2,3]). The distributions for B = 0 and U = 0 significantly differs from the ones obtained for B = 0, U_t = -5 kV, and B= 0.45 T, U_t = 0.

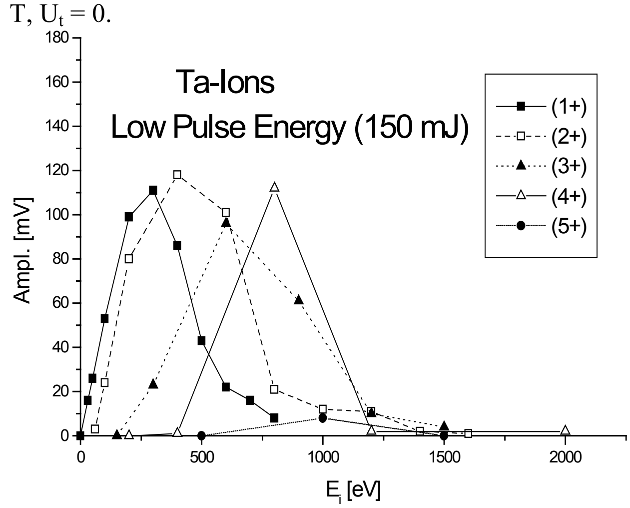

Figure 4 A tipical IEA spectra for a laser pulse of 150 mJ energy irradiating a Ta target at LNS.

The application of U_t = -5 kV results in the decrease of the maximum velocity of ions from the original value of (4.5-5) $\bullet 10^7$ cm/s to about $2\bullet 10^7$ cm/s but a significant fraction of the ions is lost. For W ion velocity of $2.5\bullet 10^6$ cm/s the intensity in the case B = 0, U_t = -5 kV is about 5 times lower then in the case B = 0.45 T, U_t = 0; the amplitudes for B = 0, U_t = 0 and B = 0, U_t = -5 kV are similar in that range, whereas many more fast ions are present in the case B = 0, U_t = 0 [9].

4 THE HYBRID SOURCE

The assembly of the hybrid ion source will be carried out in 2002 during the summer stop. In fig. 5 a lateral view of the SERSE beamline is shown along with the laser beamline. A displacement system will be installed inside the plasma chamber; it has been tested to continuously irradiate a sample on fresh surface. High repetition rate (30 Hz) was offline tested for hours. A typical emitted plume is shown in fig. 6. The Nd:YAg laser will be aligned onto the target, by means of a He-Ne laser, and a focusing lens will be placed at about 20 cm from the 0° flange of the magnet, in order to have a beam spot dimension variable from 1 to 8 mm at the target position.

The tests of the hybrid source will be limited not only to the production of highly charged heavy ions, but also to the study of ECRIS plasma in such a regime. In fact the perspective which can be opened by the new generation of ECRIS as the GyroSERSE source [10] is attractive, because their larger plasma length and higher plasma density will make less critical the limits on some parameters of the LIS and about one order of magnitude higher energy will be allowed. The larger plasma energy content $n_e kT_e$ will be much higher and higher beam currents injected by the LIS may be absorbed by the plasma.

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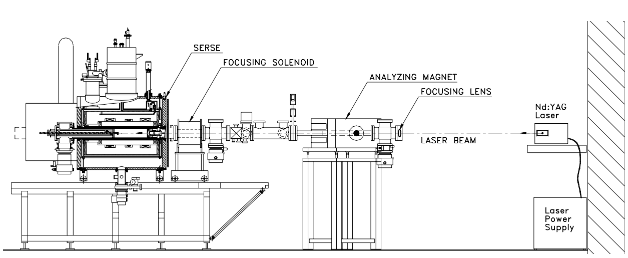

Figure 5: Lateral view of SERSE installation.

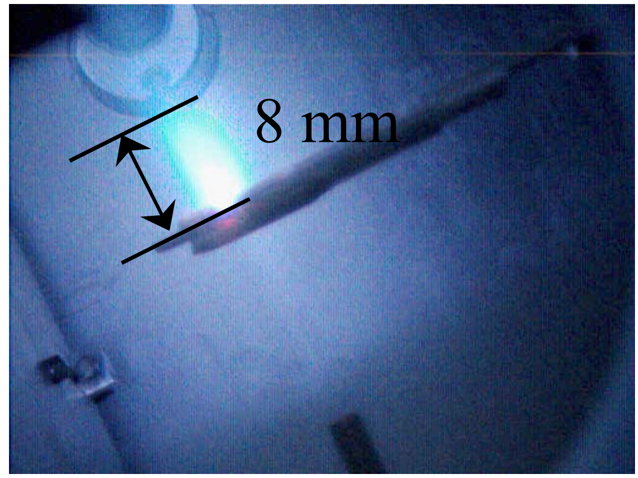

Figure 6: Plasma plume from the target (30 Hz repetition rate).

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