Emittance characterization of ion beams provided by PLATONE accelerator

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Abstract

Laser ion sources offer the possibility to have ion beams that can be useful as injector for particle accelerators. In this work, we studied the geometric quality of ion beams produced by the PLATONE accelerator. It is a LIS source and an electrostatic accelerator. It consists of ns pulsed KrF laser which works at the intensity of 10^8-10^{10} W/cm^2 and a vacuum chamber where the ions are extracted from the plasma plume and accelerate by a double gap accelerating system. The accelerating voltage applied in DC mode was 60 kV. The beam characterization was performed by the Pepper Pot method with the use of radio-chromic films as sensible target. The measurements were performed by varying the geometric configuration of the anode (the extracting electrode) for the accelerating system. The lowest value found for the normalized emittance was 0.20 πmm mrad.

Introduction

In the last decade, new techniques to produce particle beams make use of the interaction between high power femtosecond laser pulses and thin foils [1]. In contrast with other techniques, these give the advantage to obtain highly collimated and energetic particle beams from the rear of the target surface. Depending on the laser parameters, two mechanisms seems to be responsible of the ion acceleration: target normal sheath acceleration (TNSA) [2] and radiation pressure acceleration (RPA) [3]. Despite of the high quality beams obtained through TNSA and RPA systems, older and well known techniques, such as pulsed laser ablation (PLA), still play a fundamental role for applications, since the former have extremely high total costs of ownership and require large space for its working.

It is well known that the use of the PLA technique allows to easily obtain ions from solid targets, whose energy can be easily increased by applying post acceleration [4, 5]. Today it is possible to easily arrange laser beams at intensities of the order of 10^8-10^{10}W/cm^2 and ns pulse duration that, interacting with solid matter in vacuum, produces hot plasmas [6] at high temperature and densities, of the order of tens of eV.

Thermal interactions, adiabatic expansion in vacuum and Coulomb interactions are responsible for the primary ions acceleration in plasma. By applying post acceleration, it is possible to extract from the plasma plume specific charged particles. This idea can be applied to plasmas of moderate density owing to their low electric conductivity.

Nowadays, ion beams of moderate energy have a wide range of applications, from scientific to industrial ones [7-9].

So many laboratories, as well as the LEAS, are involved to develop accelerators of very contained dimensions, easy to be installed in little laboratories and hospitals. The use of ion sources facilitates the improvement of ion beams of moderate energy and good geometric qualities.

There are many methods to obtain particle beams; the application of pulsed laser ablation (PLA) technique (the one that we adopt in this work) allows to get ions from solid targets, without any previous preparation, whose energy can be easily increased by post acceleration systems [4-5]. In this way, plasma can be generated from many materials, also from refractory ones.

In this work, we characterize the ion beams provided by a laser ion source (LIS) accelerator composted by two independent accelerating sectors, using an excimer KrF laser to get PLA from pure Cu target. Using a Faraday cup and a pepper pot system, we studied the extracted charges and the geometric quality of the beams.

Materials and methods

The Platone accelerator is a LIS source with an electrostatic system to extract and accelerate the ions. It consists of a KrF excimer laser operating in the UV range (λ: 248 nm, τ: 25 ns) to get PLA from solid targets and a vacuum chamber device for the expansion of the plasma plume, the extraction and acceleration of its ion component. The maximum output energy of the laser is 600 mJ. The angle formed by the laser beam with respect to the normal to the target surface is 70^o. Focalizing the laser beam by a thin lens of 15 cm length, the spot area onto the target surface was fixed at 0.005 cm^2, obtaining an irradiance of the order of 10^8 W/cm^2.

The accelerating system consist of three parts[X]: an expansion chamber (EC), closed around to the target support (T) at a positive high voltage (HV) of +40 kV, a pierce ground electrode (GE) placed at 3 cm distance from EC and a third electrode (TE) placed at 2 cm from GE connected to a power supply of negative bias voltage of 20 kV. In this way it is possible to generate an intense accelerating electric field in two gaps, between EC-GE and GE-TE. Four capacitors of 1 nF, between EC and ground, stabilize the accelerating voltage during the fast ion extraction.

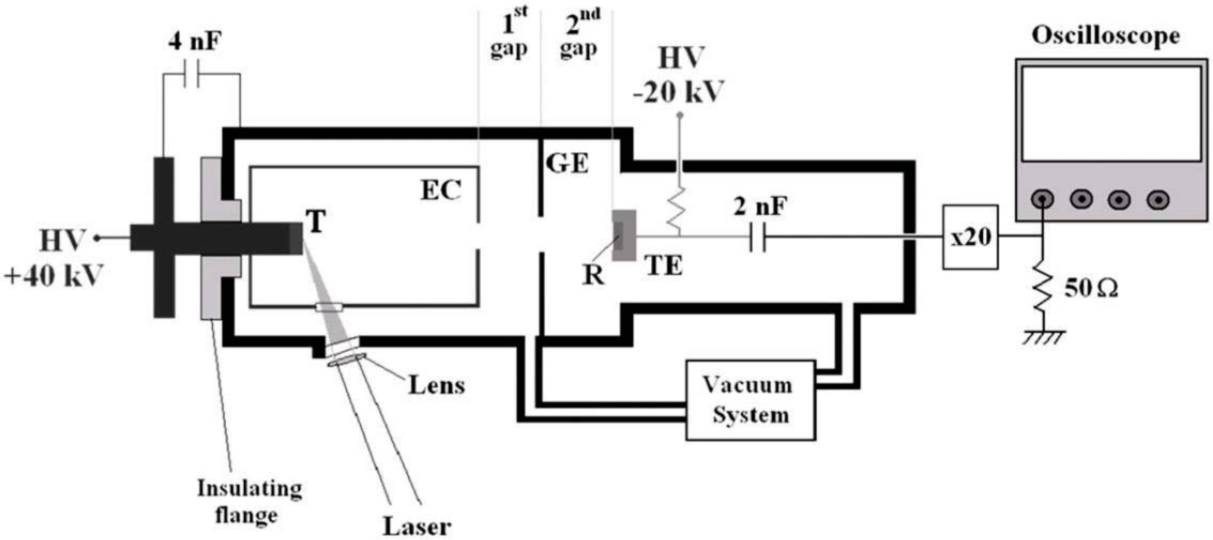


Figure 1: Schematic drawing of the LIS accelerator (T: Target support, EC: Expansion Chamber, GE: Ground Electrode, R: Radiochromic, TE: Third Electrode)

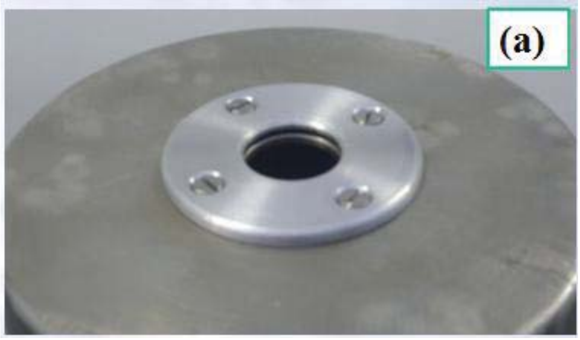
The TE is also utilized as Faraday cup collector; in fact it is connected to the oscilloscope by a HV capacitor (2 nF) and a voltage attenuator, x20, in order to separate the oscilloscope from the HV and to suit the electric signal to oscilloscope input voltage. The value of the capacitors (4 nF) applied to stabilize the accelerating voltage and the one of the capacitors (2 nF) used to separate the oscilloscope from the HV are calculated assuming a storage charge higher that the extracted one. Under this condition, the accelerating voltages during the charge extraction is constant as well as the oscilloscope is able to record the real signal.

TE is not able to support the suppressing electrode on the cup collector and therefore secondary electron emission, caused by high ion energy, is present.

In order to compare the efficiency of the extraction and the geometric quality of the beams we varied the configuration of the EC (the extracting electrode) by modifying the hole. We mounted a grid and so we obtained three configurations (see Fig. 2):

- extraction hole without grid **(a)**,
- extraction hole with a plane grid **(b)**,
- extraction hole with a curved grid, radius 0.8 cm **(c)**.

The attenuation factor of the grid is 20%. Using TE as Faraday cup and a pepper pot system (see Fig. 4), we studied the extracted charges and the geometric quality of the beams.



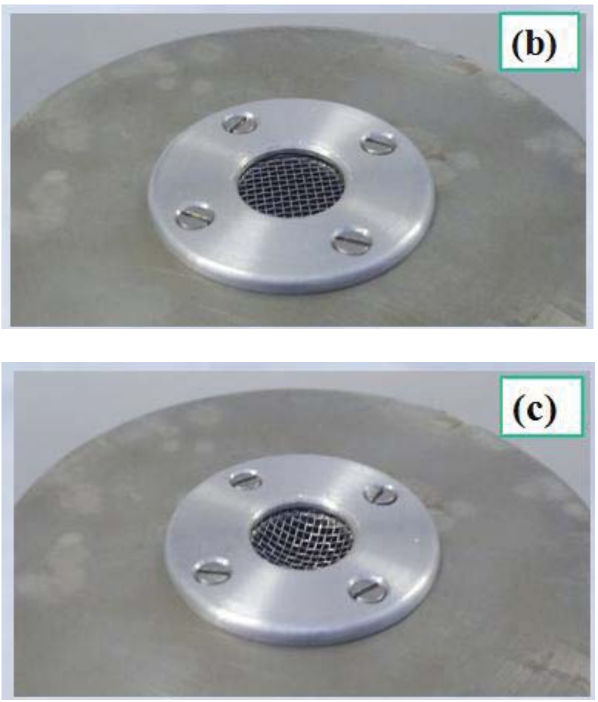


Figure 2: Photos of the extraction hole without a grid (a), with a plane grid (b) and with a curved grid (c).

Results

The value of the laser irradiance used to produce ion beams was 1.0x10^{8}W/cm^{2} and the ablated target was pure (99.99 %) disk of Cu. Figure 3 shows the extracted charge for different accelerating voltage values for the three configurations. The Faraday cup was placed at 25 cm from the target.

A measure of the beam quality could be the product of the beam's width and divergence, were the divergence relates to the random or thermal velocity spread. So, for the geometric characterization of the beam we performed emittance measurements by the pepper pot technique [10].

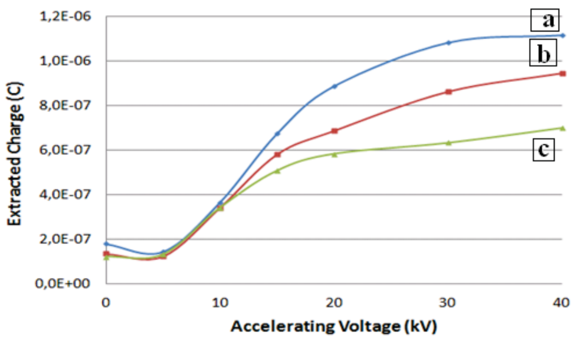


Figure 3: Extracted charge for different anode configurations.

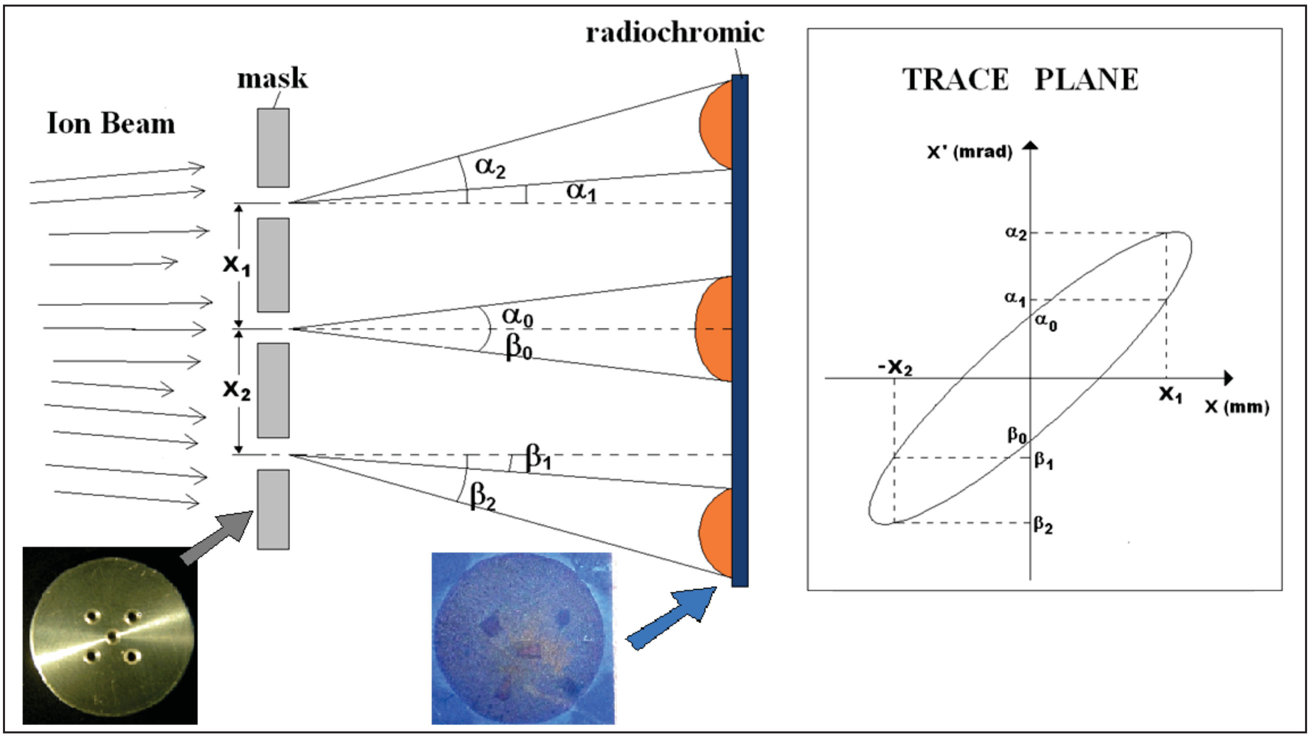


Figure 4: sketch of the system used to measure the emittance value by pepper pot technique.

Figure 4 shows a sketch of the system used to measure the emittance value by pepper pot technique. The mask we used has 5 holes of 1mm in diameter and it was fixed on the GE. One hole is in the centre of the mask and 4 holes are at 3.5mm from the centre. We used as photo-sensible screen radiochromic films (R) Gafchromic EBT, placed on the TE.

Radiochromic detectors involve the direct impression of a material by the absorption of energetic radiation, without requiring latent chemical, optical, or thermal development or amplification. A radiochromic film changes its optical density as a function of the absorbed dose. This property and the relative ease of use, led to adopt these detectors as simple ion beam transverse properties diagnostic tools. So, the ion beam after the mask imprinted the radiochromic film and then it was possible to measure the divergence of all beamlets. The divergence values allowed to determinate the beam area in the trace plane TPx. For a z-axis beam propagation, the x-plane emittance ε_x is $1/\pi$ times the area Ax in the TPx occupied by the points representing the beam particles at a given value of z.

So, we applied 250 laser shots to imprint the radio-chromic films. We measured the emittance for the three different anode configurations.

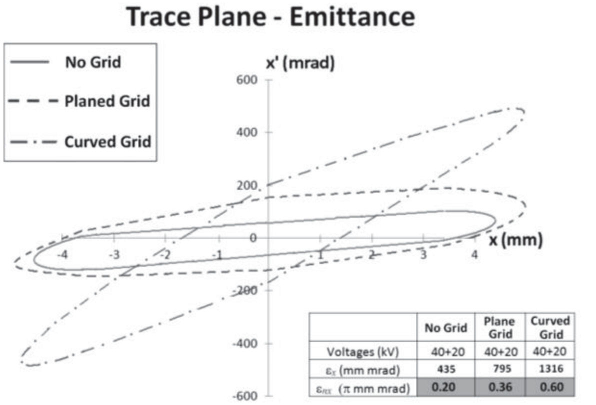
Discussion

By the radiochromic images we draw the ellipses in the trace plane and we calculated the area. The results are shown in Fig. 5 were it is inserted a table of the emittance values found. The obtained results show that the best configuration to have a low emittance value is the hole without the grid.

Therefore, by Liouville's theorem it is known that the area occupied by the particle beam in PPx is an invariant quantity and the normalized emittance is:

$$\varepsilon_{nx} = \beta\gamma\, \varepsilon_x \qquad (1)$$

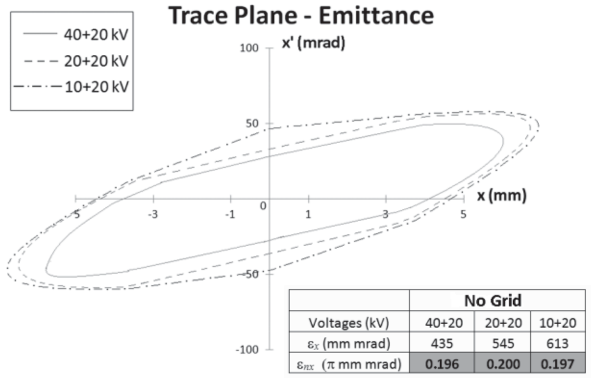
where β=v/c and γ is the Lorentz factor.



	No Grid	Plane Grid	Curved Grid
Voltages (kV)	40+20	40+20	40+20
ε_x (mm mrad)	435	795	1316
ε_{nx} (π mm mrad)	0.20	0.36	0.60

Figure 4: Emittance diagram in the trace plane for different anode configurations.

We perform measurements of emittance in the "no grid" configuration for different accelerating voltages. The obtained values of the area in the TPx resulted of 613, 545 and 435 mm mrad for 30, 40 and 60 kV of total accelerating field, respectively (Fig. 5).



	No Grid		
Voltages (kV)	40+20	20+20	10+20
ε_x (mm mrad)	435	545	613
ε_{nx} (π mm mrad)	0.196	0.200	0.197

Figure 5: Emittance diagram in the trace plane for different accelerating voltage values, in "no grid" configuration.

Considering equation (1) we found the normalized emittance values. For all the applied voltage values, the normalized emittance resulted constant:

$$\varepsilon_{nx} = 0.2\,\pi \text{ mm mrad.}$$

By these results, PLATONE is very promising to be used to feed large accelerators. The challenge of the moment is to get accelerators of dimensions so small that can be easily deployed in little laboratories and hospitals.

Conclusions

The post-acceleration of ions emitted from laser-generated plasma can be developed to obtain small and compact accelerating machines. The output current can easily increase on accelerating voltage. We have also demonstrated that by two gap of acceleration it is possible to increase the ion energy avoiding to apply only one acceleration voltage of high value. Increasing the voltage of the first accelerating gap, we increased substantially the efficiency of the extracted current due to the rise of the electric field and extracting volume inside the EC. We measured the geometric characteristics of the beam by means the pepper pot technique. We found a low value for the normalized emittance of our beams, ε_{nx} = 0.2 π mm mrad.

So this study have demonstrated that our apparatus can be produce ion beam with good quality, such as low emittance. For this reason it is very promising to be used to feed large accelerators.

References

[1] M. Hegelich, S. Karsch et al, Phys. Rev. Lett., **89** (2002) 085002.

[2] S. C. Wilks, A. B. Langdon et al, Phys. Plasmas, **8** (2001) 542.

[3] T. V. Liseykina, M. Borghesi et al, Plasma Phys. Control. Fusion, **50** (2008)124033.

[4] L. Torrisi, S. Cavallaro et al, Rad. Eff. and Def. in Solids, **165** (6-10) (2010) 509-520.

[5] V. Nassisi and A. Pedone, Rev. Sci. Instrum., **74** (2003) 68.

[6] F. Belloni, D. Doria, A. Lorusso, and V. Nassisi, Rev. Sci. Instrum., **75** (2004) 4763.

[7] A. Lorusso, L. Velardi et al, Nucl. Inst. and Meth. in Phys. Res. B, **266** (2008) 2490-2493.

[8] F. Noli, A. Lagoyannis and P. Misaelides, Nucl. Inst. and Meth. in Phys. Res. B, **266** (2008) 2437–2440.

[9] M. Rosinskia, B. Badziak, P. Parys, J. Wołowski and M. Pisarek, Appl. Surf. Sci., **255** (2009) 5418–5420.

[10] J.G. Wang, D.X. Wang and M. Reiser, Nucl. Inst. and Meth. in Phys. Res. A, **307** (1991) 190-194.