Nuclear Instruments and Methods in Physics Research B 331 (2014) 23–26

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Emittance dependence on anode morphology of an ion beam provided by laser ablation

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ARTICLE INFO

Article history:
Received 25 September 2013
Received in revised form 20 October 2013
Accepted 25 October 2013
Available online 27 January 2014

Keywords:
Laser ion source
Emittance
Faraday cup

ABSTRACT

In this work, we studied the characteristics of ion beams generated by Platone accelerator in different anode configurations. The accelerator is a laser ion source with two gaps which accelerate the ions in cascade. The laser is a ns pulsed KrF able to apply irradiances of 10^9–10^{10} W/cm^2. The target ablated was pure disk of Cu. The accelerating voltage applied in this work was 60 kV. The emittance evaluation was performed by the pepper pot method utilizing radio-chromic films, EBT Gafchromic, as sensible targets. The study was performed by varying the geometric configuration of the anode (the extracting electrode), modifying the hole morphology, e.g. a plane and curved grid were mounted in order to change the extraction configuration. The results were compared with the ones obtained with the extraction hole without any grid. For the normalized emittance the lowest value was 0.20π mm mrad.

1. Introduction

Recently, new techniques by interaction between high power femtosecond laser pulses and thin foils [1] are employed to produce ion beams. In contrast with other techniques, these give the advantage to obtain highly collimated and energetic particle beams from the rear of the target surface. 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 at intensities of the order of 10^8–10^{10} W/cm^2, produces hot plasmas [4] from which it is possible to extract ion beams whose energy can be increased by applying post acceleration [5,6]. This idea can be applied to plasmas of moderate density. In presence of accelerating field the low electric conductivity diminishes the formation of arcs.

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

In this work, we characterize ion beams provided by a laser ion source (LIS) accelerator composed by two independent accelerating sectors, using an excimer KrF laser to get PLA from pure Cu target. Using a pepper pot system and a Faraday cup, we characterized the geometric quality of the beams and the extracted charge. In particular, since these qualities are affected by the extracting field, we modified the anode morphology on the first accelerating sector, in order to understand how these changes influence the resulting beams.

2. 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 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°. Focalizing the laser beam by a thin lens of 15 cm length, the spot area onto the target surface was 0.005 cm^2, obtaining an irradiance of the order of 10^8 W/cm^2. The target was pure disk (99.99%) of Cu.

The accelerating system consists of three parts, Fig. 1: (i) an expansion chamber (EC) placed around the target support (T) at a positive high voltage (HV) of +40 kV; (ii) a pierce ground electrode (GE) placed at 3 cm distance from EC; (iii) a third electrode (TE, 30 mm diameter) placed at 2 cm from GE connected to a

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0168-583X/$ - see front matter
http://dx.doi.org/10.1016/j.nimb.2013.10.079

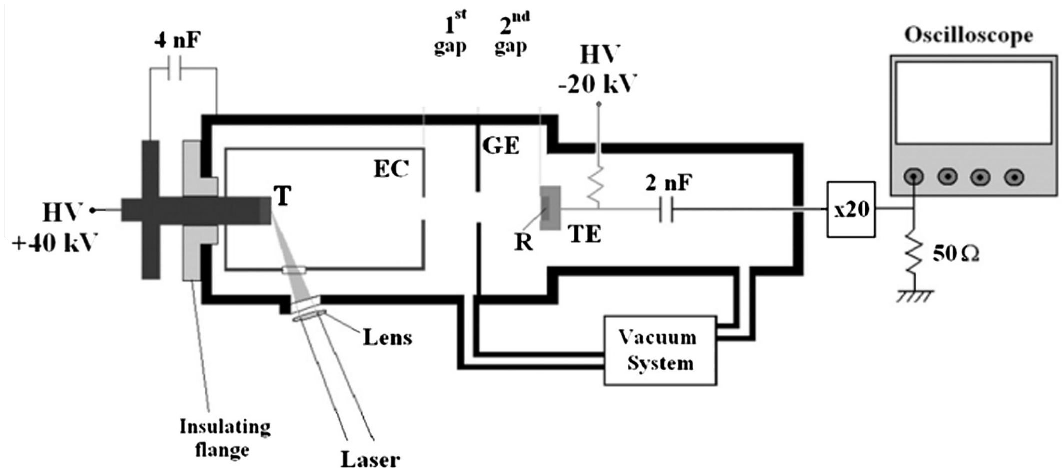

Fig. 1. Schematic drawing of the LIS accelerator (T: Target support, EC: Expansion Chamber, GE: Ground Electrode, R: Radiochromic, TE: Third Electrode).

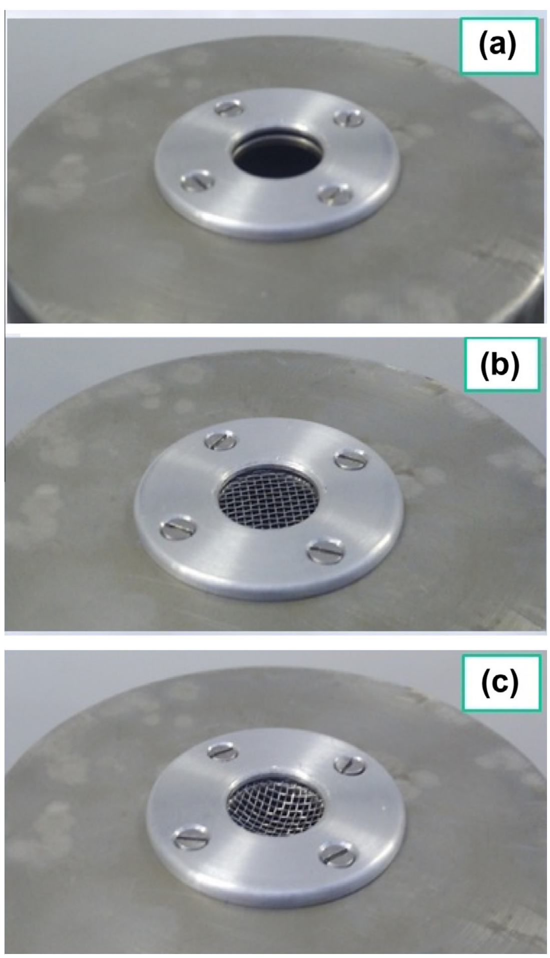

Fig. 2. Photos of the extraction hole without a grid (a), with a plane grid (b) and with an inward curved grid (c).

power supply of negative bias voltage of 20 kV. The EC and GE holes have both a 15 mm diameter. 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.

TE is also utilized as Faraday cup collector. It is connected to the oscilloscope by a HV capacitor (2 nF) to separate the oscilloscope from the HV and a voltage attenuator, $\times 20$, to suit the electric signal to oscilloscope voltage. The value of the capacitors applied to stabilize the accelerating voltage (4 nF) and to separate the oscilloscope from the HV (2 nF) 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 leading to register about 40% more charge on FC (with an applied voltage of 40 kV).

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):

Fig. 2 shows the photos of the anode:

- Extraction hole without grid (a).
- Extraction hole with a plane grid (b).
- Extraction hole with an inward 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 [10], we studied the geometric quality of the beams and the extracted charges.

Fig. 3 shows a sketch of the system used to measure the emittance value by pepper pot technique. The mask we used was made of aluminum, in order to evacuate the charges impinging on its surface. It has 5 holes of 1 mm in diameter and it was fixed on the GE. One hole is in the center of the mask and 4 holes are at 3.5 mm from the center. We used as photo-sensible screen radiochromic films (R) Gafchromic EBT, placed on 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 determine 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.