OPERATION OF A LASER-ION SOURCE IN A VAN DE GRAAFF

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Abstract

By a new version of our laser-ion source /1/ long-term runs are now possible. This is achieved by using a rotatable cylindrical target. Mounted in the terminal of a small Van-de-Graaff /2/, ion currents (C-ions) up to 18 mA were accelerated. The ion currents just behind the source were in the range of one ampere. By magnetical and/or TOF analyses charge states up to 14+ of Au-ions could be observed. For the transversal emittance an upper limit of 44 π mm mrad at a voltage of 1.6 MV was evaluated.

1. Introduction

In this paper an improved version of our laser-ion source /1/, /3/ is presented. The principle is as follows: by the interaction of a powerful pulsed laser beam with a solid target, a plasma containing multiply charged positive ions is generated. By means of suitable extraction electrodes ion beam currents in the order of one ampere can be extracted. A detailed description of the former source, the principles and the studies done with it are also shown in ref. /1/ and /3/. Due to evaporation of target material during each laser shot, craters with increasing depth occur on the target surface. For proper focussing conditions for the laser beam the target must be moved to get a flat surface again. For this reason a long living cylindrical target was introduced which can be moved by a vacuum stepper motor, controlled by fibre optics. A part of the measurements were performed with the old flat and other with the new cylindrical configuration. The ion source output is not influenced by this. As the quality and quantity of the ion beam depends strongly on the structure of the extraction we have studied this in detail; the results are shown in this paper.

2. Experimental Set-up

In comparison to our former arrangement /1/ we have added 3 more accelerator tubes, a

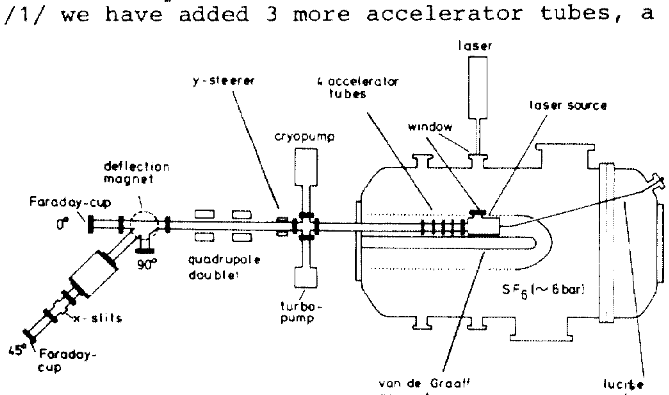

Fig. 1: The arrangement of the laser, the Van de Graaff, the ion source, the beam-line system with the bending magnet and the charge collectors.

bending magnet and a magnetical quadrupole dublett (see fig. 1). The bending magnet allows additional charge state analysis and control of TOF-measurements.

The beam from a pulsed Nd:Yag-laser (1064 nm, up to 300 mJ in ~ 9 ns) passes through a thick optical window (thickness 19 mm), through the pressurized insulating gas (SF_6, up to 6 bar) and a second identical window into the ion source chamber. The laser-produced ions are passing 4 NEC standard accelerating tubes (80 cm full length). Measurements were done with terminal voltage up to 1.6 MV. Ion current signals were measured by fast charge collectors and observed with a storage oscilloscope. The trigger signal is delivered directly from the laser. Magnetical analysis of the ion beam was done using the high voltage of the Van de Graaff, while for TOF-measurements the NEC-tubes were shortened out and the velocity of ions is mostly determined by the extraction voltage and the charge state.

The new ion source is shown in fig. 2.

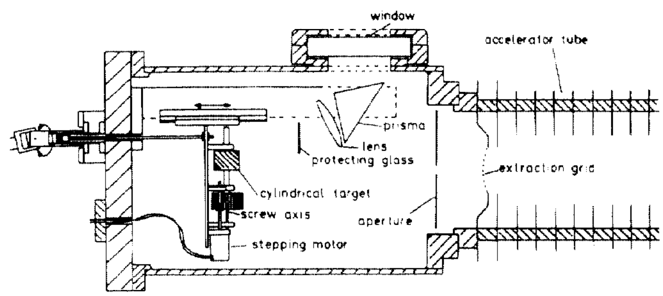

Fig. 2: The ion source with the new cylindrical target. The target can be rotated in small steps and is moved in axial direction at the same time. The spherical extraction grid used during some measurements is also shown.

After passing the window in the source chamber wall, the laser beam is bent by a 90°-prism and focussed by an aspherical lens onto the target. A thin glass plate protects the lense from evaporated target material. A mechanical feedthrough allows fine adjustment of the target cylinder for proper focussing of the laser beam. The target has cylindrical shape and can be rotated by a vacuum stepper motor, which is controlled from outside the Van de Graaff by fibre optics. During rotation a screw axis moves the target in axial direction simultaneously. By these movements, the laser craters produce a spiral shaped curve on the surface of the target cylinder.

3. Measurements and Results

3.1 Maximum Ion Yield

For measuring the total ion yield (all charge states) a device as shown in fig. 3 was mounted at the aperture of the source. The source is on extraction potential (typ. 2 to 6 KV) and therefore also the first metal grid. The second grid is on ground potential. The optical transmission of each grid is 92%. The charge collector is on positive potential

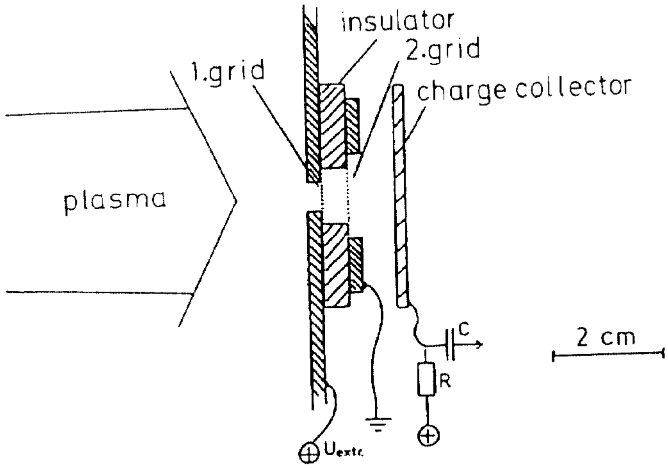

Fig. 3: The extraction configuration for measurement of the ion source output. Extraction diameters were 5 mm (as shown here) and 40 mm.

(300-500 V). If the proper extraction voltage is supplied, all ions entering the extraction aperture are separated from the plasma. The ion yield obtained in these measurements depends on the laser flux; the result with Ta-ions is shown in fig. 4.

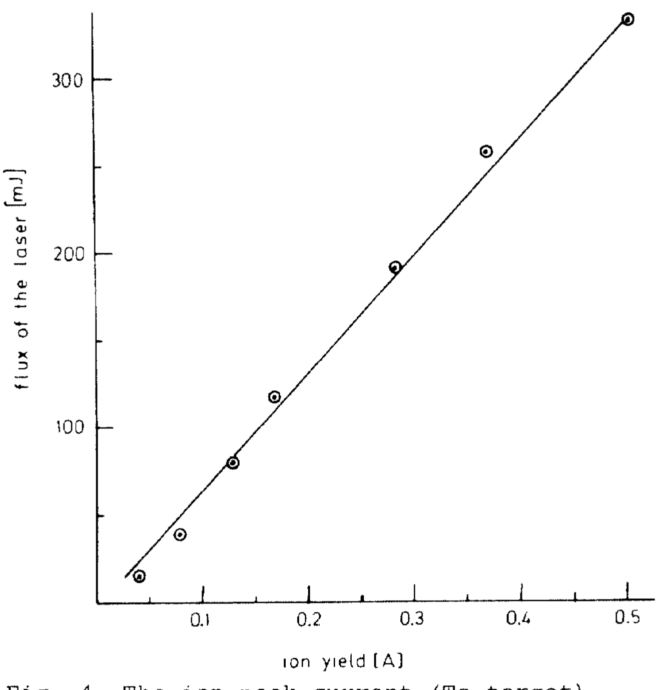

Fig. 4: The ion peak current (Ta-target) versus laser flux.

It can be clearly seen, that with further increase of the laser flux a still higher ion yield is expected. The highest ion yield (peak current 3 amperes) had been observed with a Ni-target. The typical ion pulse length is about 5 μs.

3.2 Acceleration of Laser-produced Ions

In order to accelerate at least part of the ions produced from the source, we made several tests with different extraction configurations. Due to the space charge of high ion currents and the limited acceptance of the accelerator tubes used two parameters are of great importance:

i) a high electrical gradient just at the extraction,

ii) proper starting conditions for the ions.

Fig. 5 shows different extraction configurations tested. The best results were achieved with the ionical extraction (c).

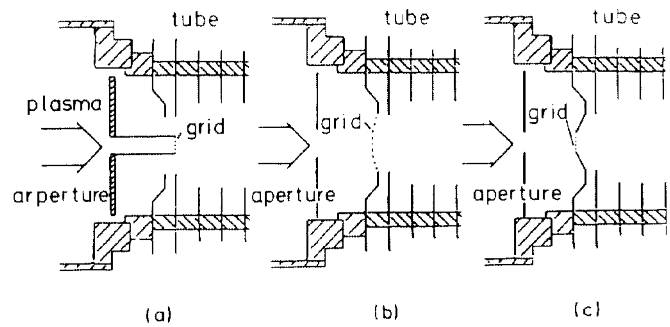

Fig. 5: The different extraction configuration tested.
(a) flat grid without focussing conditions. Aperture 10 mm diam.
(b) spherical grid. Aperture 16 mm diam.
(c) conical shape. Aperture 10 mm diam

In case of (c) with an aperture of 10 mm the accelerated ion currents were about 17 mA (C-target, all charge states, 1.6 MV) with a pulse to pulse stability of about 10%. Larger extraction apertures (used in (b)) did not increase the accelerated current but caused instabilities in the ion current and tendency towards sparking. Extraction (a) was stable like (c), but the maximum current was about a factor of 10 less.

3.3 Transversal Emittance of Accelerated Ion Beam

In order to get information on the quality of the accelerated ion beam, the emittance was measured by means of pepper-pot technique. The luminescence image, produced from ions passing a multiple hole aperture on a ZnS-routed glass plate, was photographically recorded. This arrangement was set up at the 0°-beam line (see fig. 1). At a voltage of 1.3 MV an ion current of 0.3 mA is contained in an emittance region of 10 x 4 mm mrad. The total measured ion current is restricted by the geometry to an emittance region of 44 π mm mrad.

3.4 Charge States of Ions

The measurements of charge states were done by TOF and/or magnetical analysis. We have measured charge state distributions of C, Al, Fe, Co, Ni, Cu, Ag, In, Ta, Au and Pb. In the case of Au the highest charge state (14+) was observed. The maximum charge states of other elements, except for C andAl, was at least 10+. Always all charge states from 1+ up to the highest were present. The results in detail are shown in ref. /3/. The limitation fo:

higher charge states seems to be only due to the maximum laser flux, which is estimated in our experiments to about 10^{12} W/cm^2.

As the relative amounts of the different charge states are not accurate with the TOF-measurements (ref. /3/), we have evaluated the exact values with the help of the analyzing magnet. The charge state distributions with this method, obtained from C- and Au-targets at laser pulse energies of 40 mJ and 300 mJ, are listed below.

charge state	relative ion yield, normalized to the lowest charge state observed			
	C (40 mJ)	C (300 mJ)	Au (40 mJ)	Au (300 mJ)
1+	1	1	-	-
2+	0.54	0.52	1	1
3+	0.24	0.45	0.10	0.23
4+	0.015	0.19	0.036	0.18
5+	<0.003	0.025	0.0028	0.10
6+		0.0022	≤0.0002	0.031
7+			<0.0002	0.025
8+				0.013
9+				0.006
10+				0.003
11+				0.0006
12+				≤ 0.0001
13+				< 0.0001

Due to the limited magnetical rigidity, 1+ for Au could not be measured.

3.5 Long-term Run

To evaluate the behaviour of the laser ion source and the Van de Graaff during long-term operation we performed a test of 12 hours. In this test the terminal voltage was set to 1 MV, and extraction (c) from fig. 5 with a diameter 3 mm was used. The repetition rate was 1 Hz. After such period of 10 laser pulses the cylindrical target was moved for fresh surface. The ion yield measured at 0° was 2 mA (C-target). Pulse to pulse fluctuations in the current were around 10%. During this test no spark was observed, and about 1/3 of the target cylinder was used.

4. Summary and Conclusion

We have shown that a laser-ion source is a simple ion source for production of heavy ions and can easily be operated in the terminal of a Van de Graaff. High current output and also high charge states were observed. By introducing a cylindrical target with a stepper motor we have improved the life-time of the source considerably. Ion beam quality is good enough for acceleration in a Van de Graff. Potential improvements are:

i) increase of the dimensions of the dylindrical target to increase the life-time further,
ii) use of a more powerful laser to obtain even higher charge states and ion yields,
iii) increase of the ion pulse length by suited time structure of laser pulses (e.g. packets of several laser pulses separated in time by ~10 µs).

Acknowledgement

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/2/ G. Korschinek, J. Held, A. Isoya, W. Assmann, H. Münzer, "Accelerator tube test with a 5 MV Van de Graaff", Nucl. Instr. Methods 220, pp. 82-85, (1984)

/3/ J. Sellmair, G. Korschinek, "The Munich laser ion source", Nucl. Instr. Methods A268, pp. 473-477, (May 1988)