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Self-pulsed ion beams delivered by an XeCl laser

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Abstract

Multiply-charge heavy ion pulses were extracted from a plasma produced by an XeCl excimer laser beam at a relatively low flux (~ 30MW/cm^2) focused on Si, Ge, Mg and Zn targets. An output peak current of Si^{3+} ions of 375 mA was recorded at an acceleration voltage of 200 V only. The insertion of a variable capacitance between the target holder and the acceleration electrode allows a self-bunching of the ion beam. When a W target was used, a higher incident laser flux (~ 90 MW/cm^2) was necessary in order to produce ions from it.

1 Introduction

Positive charged ions can be generated by the interaction of a laser beam with solid targets, to produce beams of interest for cyclotron accelerators [1,2]. The flux of the laser pulse must be high enough to produce a dense plasma with hot electrons. The yield of ions and their charge state depend on the target materials and on the flux and wavelength of the laser beam. Infrared lasers (CO_2, Nd:YAG) have been successfully used, but very high fluxes ($\sim 10^9$ W/cm^2) were required to obtain significative ion currents [2,3], due to a poor coupling of infrared radiation with the target.

When an intense laser beam strikes a solid target, a dense hot plasma is produced in a few nanoseconds at the target surface, due to vaporization of the target materials. Multiple ionization of the evaporated species is achieved in the plasma due to the presence of hot electrons, energized by an inverse bremmstrahlung process. When the plasma frequency matches the laser frequancy, the laser light can no more penetrate the plasma plume and the coupling of the laser light with the target stops [4].

Excimer lasers, due to their short wavelength, can efficiently heat metal targets up to their vaporization temperature at lower fluxes [5]. Moreover, the higher frequency of ultraviolet light enhances the electron heating and the efficiency of light penetration into the plasma plume.

In the present paper we present a study of the production and collection of multiply charged ions from different solid targets (Si, Ge, Mg, Zn and W) by using a pulsed XeCl excimer laser ($\lambda = 308$mm).

2 Experimental setup

The excimer laser used in this experiment was locally built. It is very compact and its preionization circuit was designed to preionize the active gas mixture only during the charging phase of the main discharge circuit. During the main discharge phase the energy stored into the internal capacitors is transferred into the active gas mixture without crossing the preionization spark-gap system. So the discharge time is shortened and the laser output power is increased. Figure 1 shows a sketch of the laser section. The preionization system is formed by 42 small spark-gaps, fixed near to the shorter electrode (E), in order to illuminate the whole discharge region. As can be seen from Fig. 1, the main discharge current does not cross the spark-gaps.

The laser beam is led into the stainless-steel vacuum chamber (Fig. 2) by a 45° tilted mirror (M) and a 30 cm focal length lens (L), which focalizes the beam on the target (T).

A 2.5 cm in diameter cylindrical grid (G) held at the target potential is inserted coaxially to the target support, in order to control the plasma

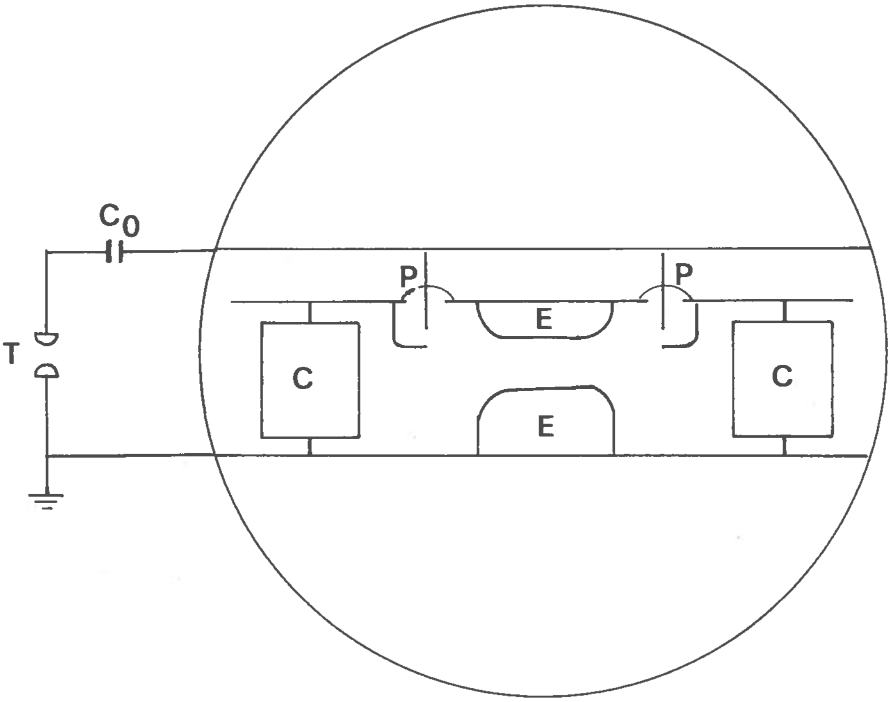

Fig.1 Laser cross section; C: internal capacitor; Co: external capacitor; E: electrodes; P: preionizators; T: spark-gap.

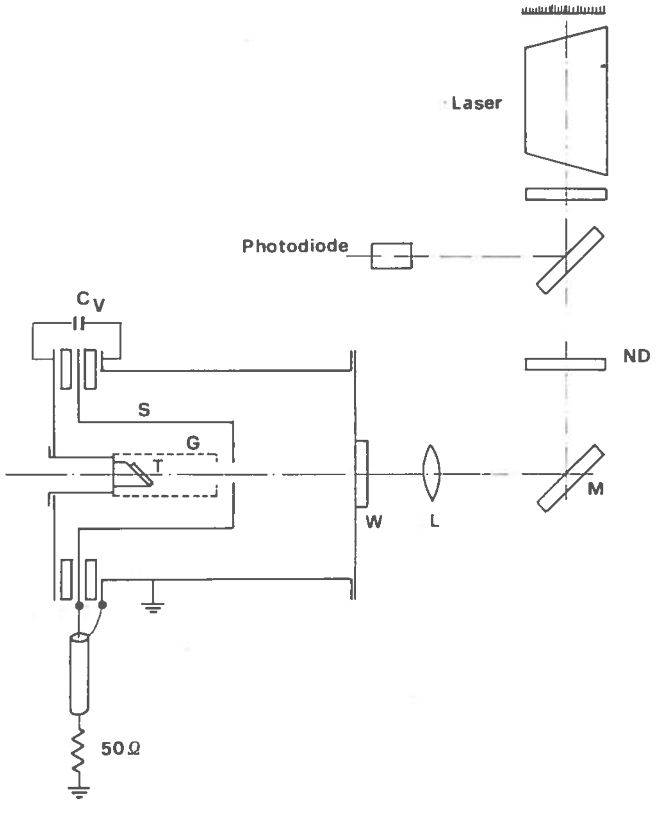

Fig. 2 Accelerating chamber; W: window; C_V: variable capacitor; L: convex lens; ND: neutral density filters; M: mirror; G: grid; S: collector; T: target.

components together with the collector. Target support is tilted at 45° in respect to the optical axis in order to lead the plasma plume on the grid. A vacuum of $\sim 10^{-5}$ mbar is maintained in the chamber by an oil-diffusion pump. The transmission coefficient of the grid is ~ 0.6.

The collector has a diameter of 3.5 cm and is placed coaxially to both the grid and the target support. A variable capacitor (C_V) is inserted between the grid and the grounded chamber envelope. The capacitance C_V can be varied from 250 pF to 1μF. The smaller capacitance values are used in order to accelerate only ions with the higher ionization degree. In fact, during its hydrodynamical expansion, the plasma crosses the grid G. The fastest ions in the plasma can be bunched by applying an acceleration voltage between the grid G and the ground electrode.

In this experiment we applied an acceleration voltage V varying from 50 to 200 V. Then, by fixing the acceleration voltage and varying the value of the capacitance, it is possible to control the charge stored into the capacitor C_V. When the stored charge results nearly equal to that contained into the fastest ion pulses, formed by the ions with the highest charge number, no further extraction of slower ions (having lower charge number) is possible due to the fall down of the acceleration voltage after the collection of the fastest components. This technique, which we call "self-pulsed beam", avoids the use of high-frequency pulsed voltage generators.

During this experiment, the laser beam energy was measured with two joule-meters (ED 500 and ED 200), while the laser pulse shape (time behaviour) was recorded with a fast photodiode (R 1328 U 02) and a digitizing oscilloscope (SCD 5000, 200 Gs/s).

3 Experimental Results

First of all we measured the energy reflected from our targets as a function of the incident flux. The laser output energy was fixed at 15 mJ/pulse. Then, the laser beam was focused utilizing a 50 cm focal length lens and the flux on the targets was varied by varying the target-to-lens distance d. The reflected energy was measured putting a joulemeter near the target. We estimated an incident flux of 16, 22 and 66 MW/cm^2 for values of d corresponding to 40, 45 and 50 cm, respectively.

Fig. 3 shows a plot of the reflectivity (ratio of the reflected to the incident energy) as a function of the flux for Zn target. It can be seen that the reflectivity decreases when the flux increases and then d approaches the the focal length of the lens. The highest reflectivity value depends on the target quality surface but its behaviour, as a function of the flux is substantially the same also for the other targets of different materials.

From Fig. 3 we can infer that at the highest fluences a dense plasma is

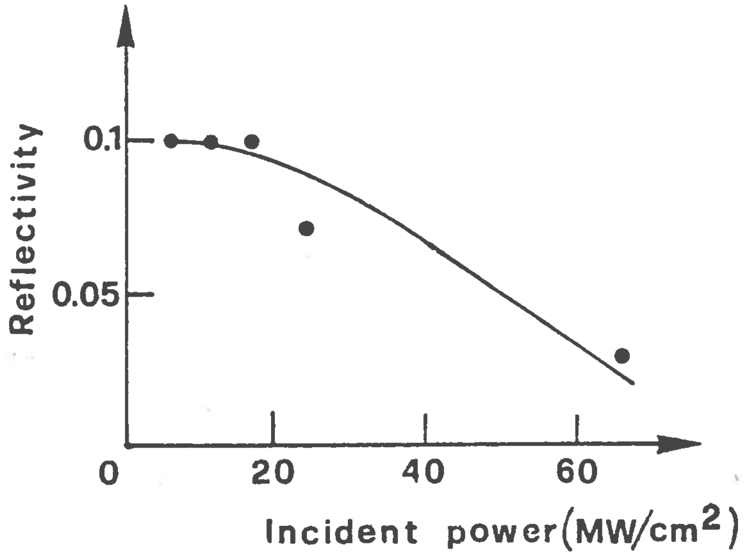

Fig. 3 Reflectivity of a Zn target as a function of the laser flux.

formed, which absorbs part of the incident laser beam.

The reflected laser beam shape (time history) was recorded with a fast photodiode. It can be seen from Fig. 4 that the reflected beam pulse is shorter than that emitted from the laser, due to the absorption which occurs after a few ns from the pulse onset, necessary to reach the threshold for plasma formation.

Then we started measurements of the ion currents produced in the source by the laser pulses.

The targets were irradiated with 30 MW/cm^2 pulses. In Fig. 5 we report the intensity of the Si ion beam pulses as a function of the time of flight (TOF) from grid to collector for an accelerating voltage of 200 V and various buffer capacitance values: 1, 0.56, 0.22, 0.2 and 0.1 μF. It can be observed that, when low value capacitors are used, the single-charged Si ions cannot be bunched. The intensity of the ion pulses was lower when accelerating voltages lower than 200 V were used.

In Fig. 6 we show the intensity of the bunched ion pulses vs TOF, for an accelerating voltage of 200 V and a capacitance value of 250 pF. It can be seen that the pulses of Si^{3+} and Si^{2+} ions are bunched and well separated in time, while the Si^{1+} ions are not bunched.

Very similar results were obtained when Ge, Mn and Zn targets were used. But, when a W target was used, a flux as high as 90 MW/cm^2 was necessary to obtain an ion pulse of intensity sufficient to be recorded.

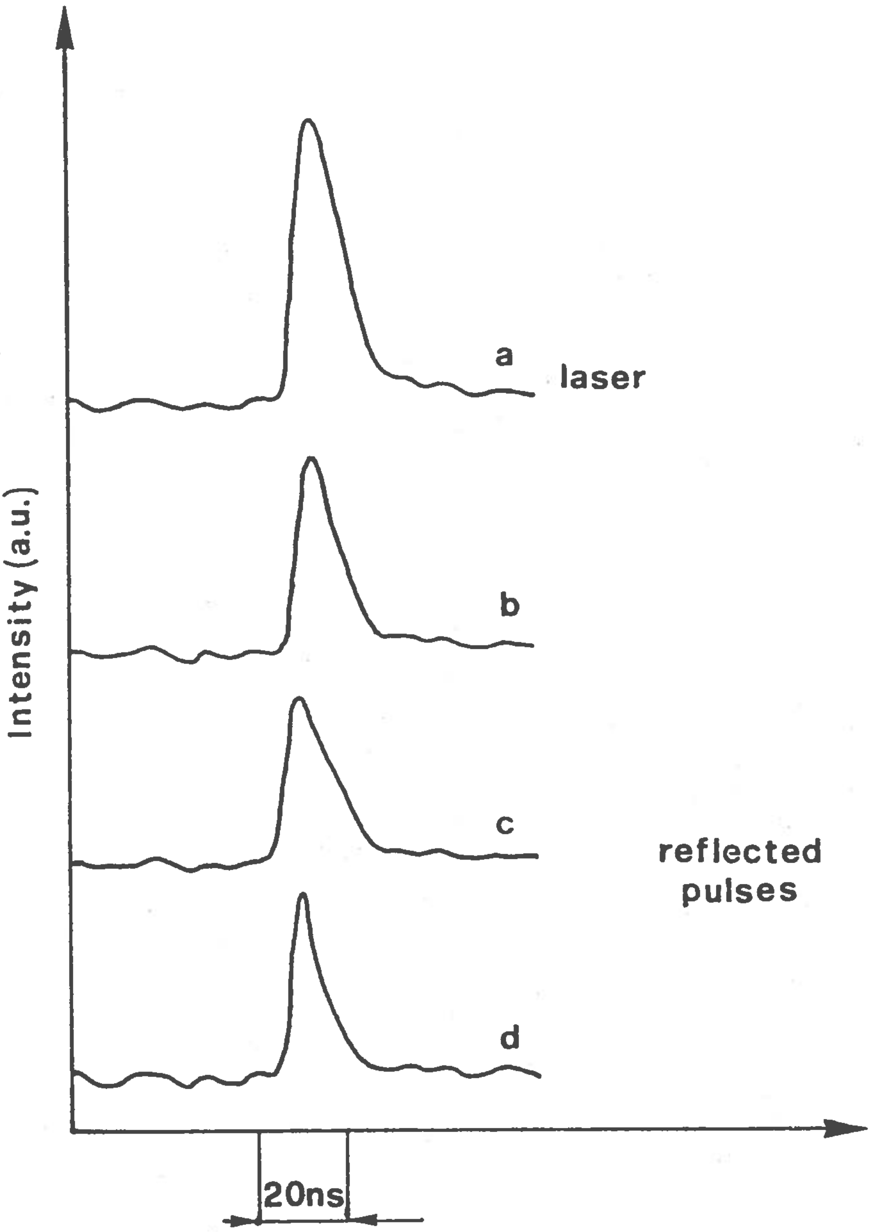

Fig. 4 Time history of the laser pulse (a) and of the reflected laser pulse from a Zn target as a function of the fluence (b) at 16 MW/cm^2, (c) at 22 MW/cm^2 and (d) at 66 MW/cm^2.

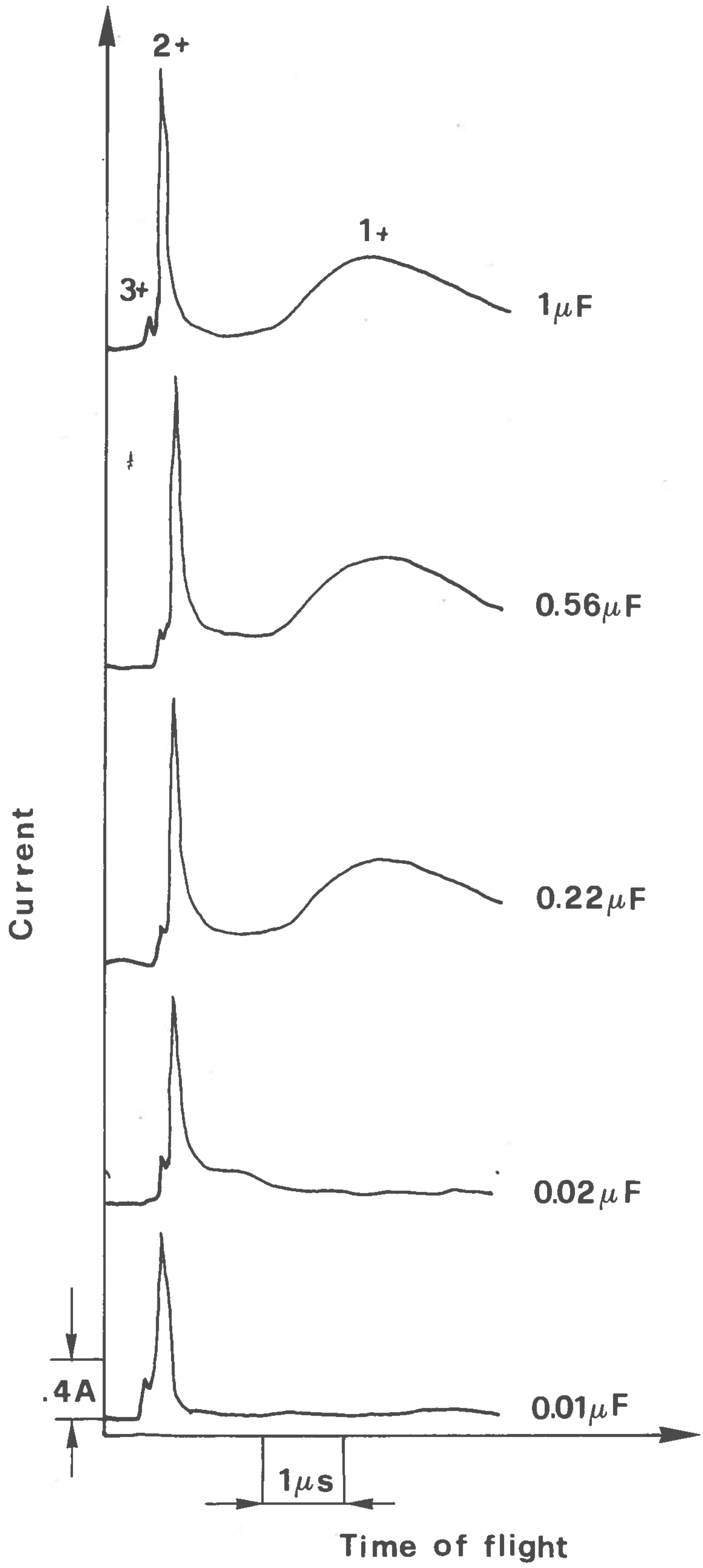

Fig. 5 Intensity of the collected Si ion beams as a function of TOF for various capacitance values.

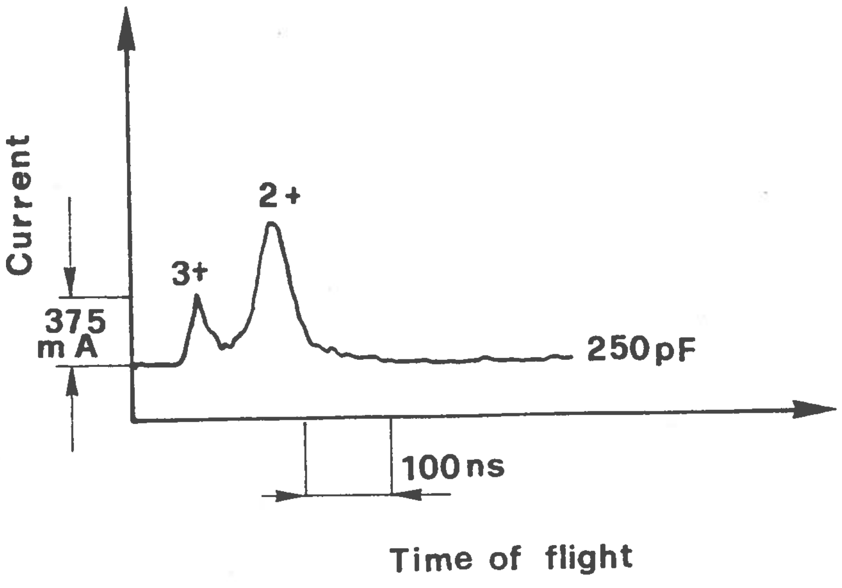

Fig. 6 Intensity of the collected Si ion beams as a function of TOF; the acceleration voltage was 200 V and the capacitance value was 250 pF.

Table 1 shows the work functions (eV) of the ions produced

Table 1

Target	1^+	2^+	3^+
Si	8.2	16.3	33.5
Ge	7.9	15.9	34.2
Mg	10.4	18.8	34.2
Zn	9.4	18.0	39.7
W	8.0		

4 Conclusions

An XeCl excimer laser was used to produce ion pulses from heavy element targets. Due to small dimensions of the test source the highest charge of the collected ions was +3.

We stress that no observable deterioration of the irradiated targets was observed after a few hours of operation at a laser repetition rate of 1 Hz.

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