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Multiple charge states of titanium ions in laser produced plasma

M SHUKLA, S BANDHYOPADHYAY, V N RAI, A V KILPIO* and H C PANT
Laser Plasma Division, Center for Advanced Technology, Indore 452 013, India
*KAMETRON Laser Group, General Physics Institute, Valivov Street, Moscow

Abstract. An intense laser radiation (10^{12} to 10^{14} W/cm^{-2}) focused on the solid target creates a hot (≥ 1 keV) and dense plasma having high ionization state. The multiple charged ions with high current densities produced during laser matter interaction have potential application in accelerators as an ion source. This paper presents generation and detection of highly stripped titanium ions (Ti) in laser produced plasma. An Nd:glass laser (KAMETRON) delivering 50 J energy ($\lambda = 0.53$ μm) in 2.5 ns was focused onto a titanium target to produce plasma. This plasma was allowed to drift across a space of ~3 m through a diagnostic hole in the focusing mirror before ions are finally detected with the help of electrostatic ion analyzer. Maximum current density was detected for the charge states of $+16$ and $+17$ of Ti ions for laser intensity of $\sim 10^{14}$ W/cm^{-2}.

Keywords. Ion source; highly charged states; titanium ions.

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1. Introduction

Nowadays, generation of a good laser ion source is an important area of research [1]. A significant improvement has been reported in the development of laser ion source, such as generation of highly charged ions at current densities of about 0.1–10 mA/cm^2. It is well known that an intense laser radiation (10^{12} to 10^{14} W/cm^{-2}) focused on a solid target creates a high temperature (≥ 1 keV) dense plasma state. As a consequence of high temperature highly stripped ions are generated in the plasma at a considerable distance from the target. Generation of highly ionized charge states require a laser of high intensity with a good beam quality. Laser ion source thus produced is found to have high beam currents of highly stripped ions. These sources are now preferred than electron cyclotron resonance ion sources for the preinjector in the large hadron collider in accelerators. Among all known lasers used for this purpose, CO_2 laser has the advantage of high efficiency that makes it most favorable for real ion source [2,3]. However, the experiments performed so far using the fundamental frequency of Nd:glass and iodine lasers suggests that short wavelength (< 1 μm) and short pulse duration (< ns) is more suitable for production of highly charged states of ions with high beam current [4]. This is due to the fact that lower the wavelength, higher is the critical density and thus increased absorption of laser radiation. Various types of metal targets ranging from low to high Z (Co, Ni, W, Pt, Au, Pb, Bi, Ta, etc.) [4,5] have been used to study the generation of highly charged ions.

In this paper we present the generation and detection of highly stripped Ti ions in laser produced plasma, when a Nd:glass laser delivering 50 J ($\lambda = 0.530$ μm) in 2.5 ns from KAMETRON laser system is focused on the titanium (Ti) target at a intensity of 10^{14} W.cm^{-2}. Titanium is chosen as target because of its high immunity towards contamination.

2. Experimental

KAMETRON laser system at General Physics Institute, Moscow consists of an oscillator followed by a pulse slicer, which provides a laser pulse of ∼3 ns duration. The laser pulse is allowed to pass through a seven pass amplifier of ∼1000 gain before it is fed into 4 successive Nd:glass amplifiers of various dimensions followed by a spatial filter, which finally delivers a beam of energy ∼150 J with a beam diameter of ∼100 mm. The fundamental laser energy is frequency doubled using second harmonic crystal to give a beam energy of ∼50 J in 2.5 ns at $\lambda = 0.530$ μm. The energy is monitored by calorimeter. Laser energy is focused onto the Ti target kept in plasma chamber evacuated at $\sim 10^{-5}$ torr, using a 100% reflecting mirror M1 and parabolic mirror M2 as shown in figure 1. The plasma is allowed to drift across a space of ∼3 m through a 20 mm hole in the parabolic mirror M2 before it is detected with the help of electrostatic ion analyzer. The details of ion analyzer are described in the next section. This configuration makes it possible to extract the highly charged and high energy ions in preference [5,6]. The signal from the ion analyzer is recorded on Tektronix oscilloscope model (744A) as shown in figure 2.

3. Detector

The schematic diagram of the electrostatic ion analyzer used as a diagnostic tool in the far expansion zone is shown in figure 2. This analyzer consists of a charge collector with a secondary electron multiplier terminated at a 50 ohms load. Signal across this load is recorded on the oscilloscope. Two slits of ∼100 μm size placed before and after the deflection plates puts a limit on the energy spread (ΔE) of the different charged states to be measured. The voltage on the deflection plates decides the energy (E/Z) of the charged particles to be detected. Once a particular energy (E/Z) is selected, it automatically provides velocity distribution for different charge states because E will be different for different charge state. The analyzer voltage is limited to ±4 kV, which is the limit of electrical breakdown inside the analyzer.

4. Results and discussion

Figures 3a and 3b shows the distribution of different charge states of Ti ions recorded with the help of ion analyzer on Tektronix 744A model oscilloscope across 50 Ohms load for the laser energy of 25 J. The analyzer voltage in this case was kept ±1250 volts. Figure 3b is expanded on the time scale. The first peak from left side correspond to the photo signal (x-ray and ultraviolet) from the laser produced plasma and it acts as the time fiducial for measurement of velocities of different charge states present in the plasma. The charge

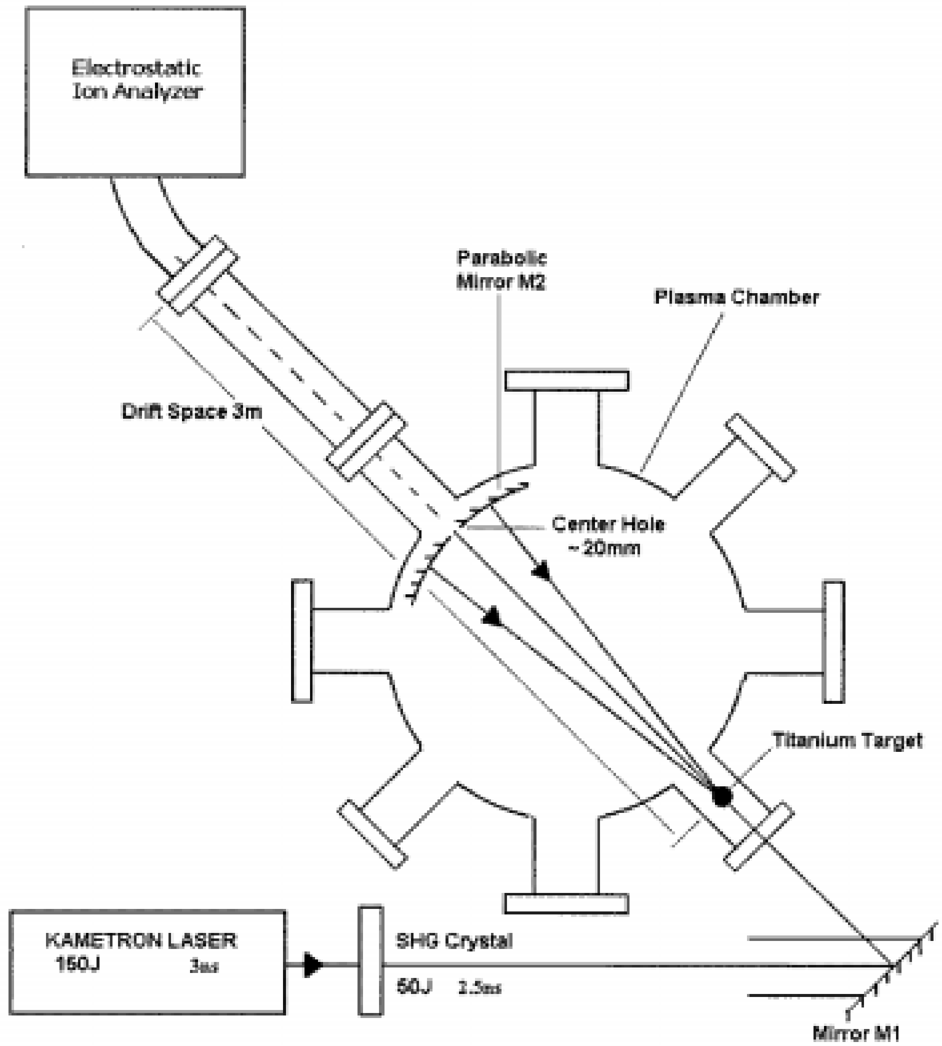

Figure 1. Schematic diagram of experimental setup.

states from +1 to +22 are seen to be easily generated and detected with the help of analyzer. It indicates that Ti plasma thus produced is a fully ionized plasma and all the charge states are detectable in the far expansion zone. Each peak corresponds to different charge state. The highest charge state (+22) reaches the analyzer first thus occurring just after the photo signal. The highest charge state has highest velocity so it can be seen that as the charge of the ions decreases the time of its reaching at the collector increases. Figures 4a and 4b shows the Ti ions spectrum recorded with the ion analyzer for laser energy of 39J and voltage ±1100 V. In this case also +22 charge state is easily detectable, that is plasma is fully ionized. The peak current density in both the cases (figures 3 and 4) is found

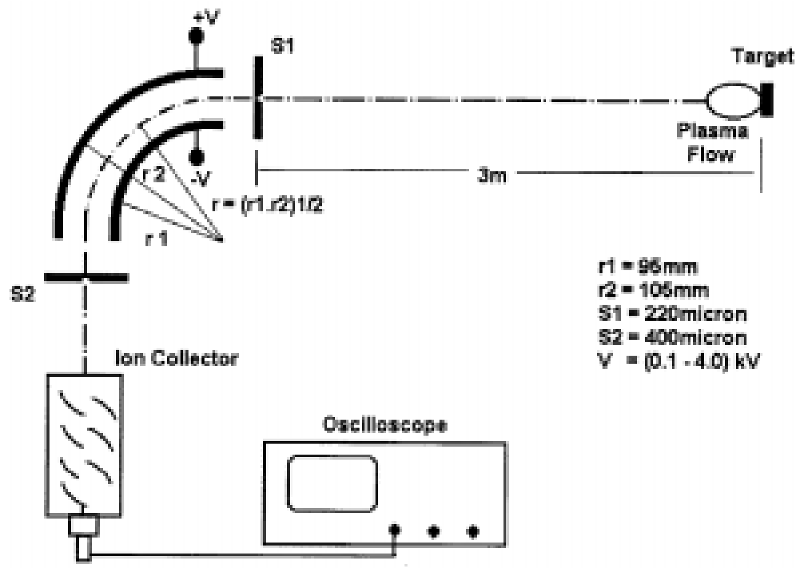

Figure 2. Ion analyzer.

to be maximum for +17 charge state. It was noted that the average peak of all the charge states increases with increasing laser energy. It was also observed from figures 3 and 4 that the peak height of +1 and +2 charge states is larger than +3 to +9 charge states, which decreases up to +9 and then starts increasing. This seems to be due to the existence of two ion groups viz fast ions (+22 to +12) and thermal ions (+11 to +1) as shown in figures 3 and 4, which is detected in the far expansion zone [7]. The temperature of the plasma, as well as ion energy, depends mainly on laser power density. The high laser intensity (10^{14} W/cm^2) focused on target results in a plasma temperature exceeding 1 keV. As the plasma expands, the electron temperature decays fast, because the laser power in this case is decreasing. The rate of recombination, which is inversely proportional to the plasma temperature, sets in. The ions pass through a comparatively dense plasma region as the temperature falls. As the system comes out of the thermodynamic equilibrium the higher charge states (+9 to +3) are destroyed rapidly than the lower ones (+1) as more and more states (higher ones) will be neutralized first due to increased force of attraction between ions and electrons. This decreases the number density of higher states to those of lower ones and results in decreased height of +9 to +3 than +2 and +1 states. The time integration of the ion spectrum (figures 3 and 4) gives existence of two ion groups with an energy distribution for fast and thermal ions. Similar observations have been observed for Ta and Pb ions in various laboratories [4,5]. In the early expansion phase the existence of fast ion group can be explained as follows. Initially a group of hot electron having temperature higher than that of the thermal electrons is generated by a collisionless absorption process near the critical surface. The movement of hot electrons generates an electric field in the plasma, which accelerates the ions because they are pulled behind the electrons. The ions with high charge states are thus guided through the recombination zone by these hot electrons. This enhances the phenomenon of charge state freezing and the ions originally present in corona of the plasma survive. However a detailed study is needed to get more information about the enhancement in the amplitude of lower charge state ions as well as charge state freezing process. Even the effect of laser energy on these processes may be interesting.

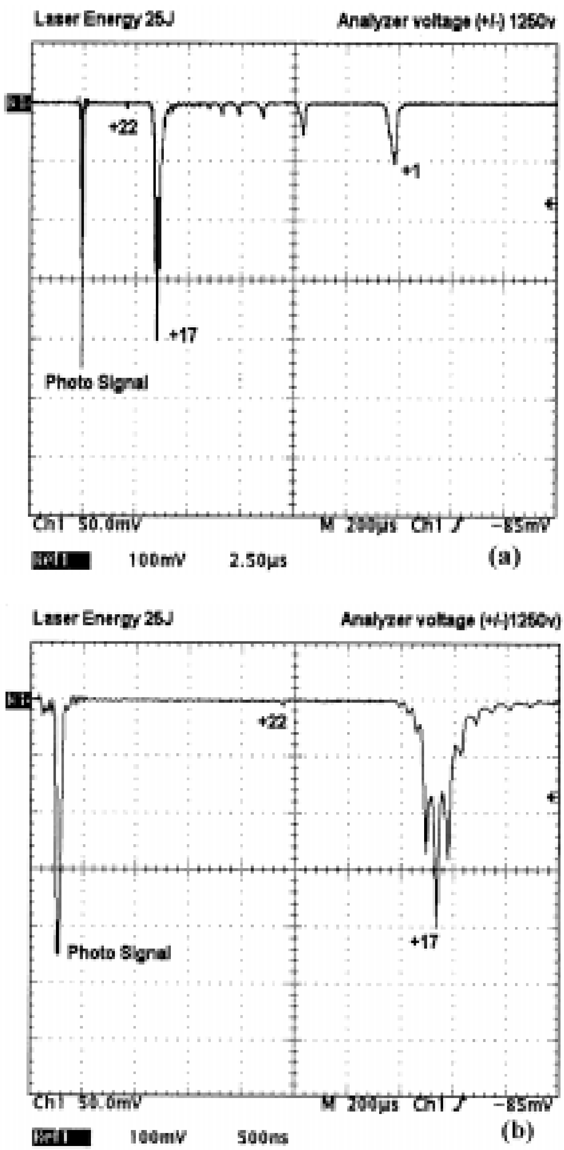

Figure 3.

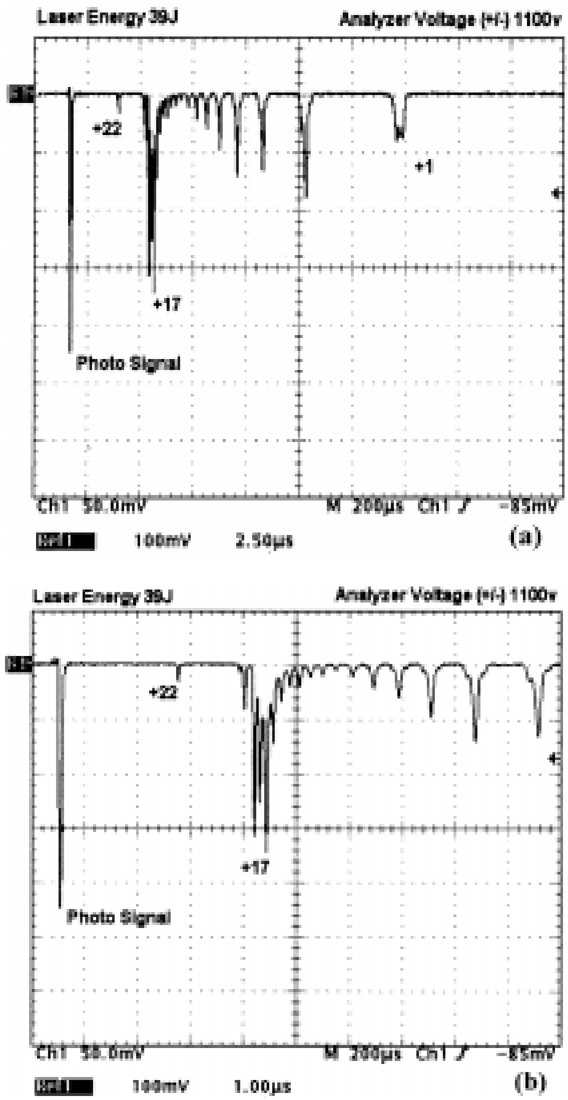

Figure 4.

5. Conclusion

In conclusion we can say that the fully ionized charge states of Ti plasma is generated and detected with the help of electrostatic ion analyzer. The experimental results prove the occurrence of highest charge state (+22) of titanium ions far from the target. These ions survive the recombination losses in the early phase of expansion. The average current density of all the charge states increases with laser energy, the peak occurring for +17 charge state.

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