ARTICLE IN PRESS

Nuclear Instruments and Methods in Physics Research B xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

Highly charged tungsten ions generated by nanosecond pulsed laser and influence of magnetic field on ion charge state

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ARTICLE INFO

Article history:
Received 15 December 2016
Accepted 21 May 2017
Available online xxxx

Keywords:
Laser generated plume
Highly charged ions
Tungsten
Magnetic field

ABSTRACT

Ions emitted from the laser generated tungsten plume were investigated with the help of ion collector (IC) and electrostatic ion energy analyzer (IEA) operating in time-of-flight configuration. Plume was generated by irradiating a plane W target with 6 ns pulsed Nd:YAG (λ = 1064 nm) laser. Laser fluence at the target was varied in the range of 3.0–19.4 J/cm^2. IC measurements showed that the amplitude of tungsten ions pulse increases with the laser fluence. IEA spectra indicate that the number of available W^{n+} ions charge states increases from 1 to 6 when laser fluence at the target was varied in the range of 3.0–19.4 J/cm^2. With the application of 0.23 T axial magnetic field at the target surface, the number of available W^{n+} ions charge states increases from 1 to 10 in the similar range of the laser fluence. In addition, molecular oxygen ions O_2^{n+} were also observed when magnetic field is applied at higher values of the laser fluence. The ion charge state enhancement is presumably due to the magnetic trapping of electrons in front of the target surface, which intensifies electron impact ionization process.

1. Introduction

Laser beam interaction with material is a simple and effective method for producing wide variety of highly charged ions. In this method a high power laser pulse focused on the target surface creates a plasma plume of the evaporated material. The ions extracted from the expanding plasma plume are then collimated into a beam. Laser ion source (LIS) has the capability to generate highly charged ions (HCI) from any solid material regardless of its chemical and physical characteristics, and can provide higher current densities of HCI as compared to the electron cyclotron resonance (ECR) ion sources [1,2]. But its major drawbacks are high ions energy spread [3,4] and high beam emittance [5,6] as compared to the discharge ion sources. Therefore, LIS needs an additional low-energy beam transport line to obtain the ion energy and ion emittance required by the downstream accelerators [7].

Recently, several laser based ion sources have been designed and extensive experimental work has been reported to optimize their performance for generation of the HCI. For instance, the production of HCI of C, Li, Ca, Al, Ti, Ni, Cu, Ag, Pb, Ta and W has been reported [7,8,4,9–11]. It has been pointed out that the charge state distribution and energy of the ions depends on the fluence [9,12] and wavelength [4,13] of the incident laser. But the systematic study on the effect of laser fluence and applied axial magnetic field on the charge state distribution of highly charge tungsten ion is not available. The investigation on ion emission from tungsten under intense electromagnetic radiation flux is quite important because tungsten is being considered as an alternate construction material for high temperature plasma research facilities and fusion reactors like JET and ITER projects [14–16]. In this study, we investigated the effects of laser fluence and applied axial magnetic field on the charge state distribution of highly charged tungsten ions emitted from a planar tungsten target irradiated with 1064 nm pulsed Nd:YAG laser. The laser fluence was in the range of 3.0–19.4 J/cm^2. The emitted ion flux was characterized with the help of ion collector and electrostatic ion energy analyzer.

2. Experimental setup

The detail of experimental setup is given elsewhere [9,12]. Briefly, the experimental setup consist mainly of an Nd:YAG laser with associated beam delivery optics, ion collector (IC), time-of-flight ion energy analyzer (TOF-IEA), ion detection and electronic system for data acquisition (see Fig. 1). The pulsed radiation from an Nd:YAG laser (wavelength = 1064 nm, pulse duration ~ 6 ns)

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http://dx.doi.org/10.1016/j.nimb.2017.05.050
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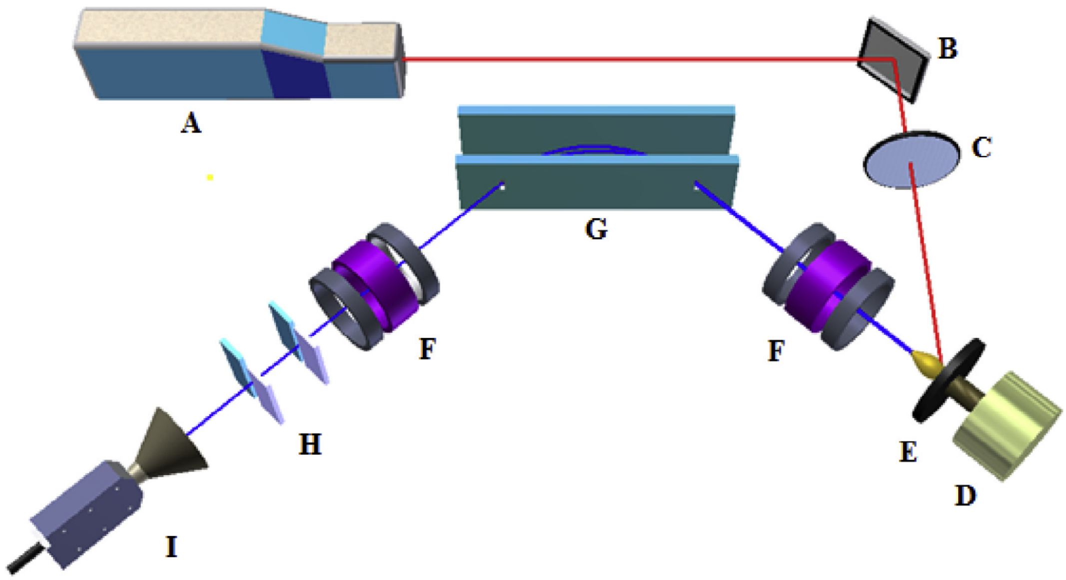

Fig. 1. Schematic of indigenously developed experimental facility (A) Nd:YAG laser, (B) Reflecting mirror, (C) Focusing lens, (D) DC motor, (E) Target, (F) Einzel lens, (G) E/q filter (H) Slits, (I) channel electron multiplier.

is focused by an optical lens (focal length $f = 50$ cm) onto the surface of a high purity (99.99%) tungsten target. Laser beam enters the vacuum through a quartz window and impinge on the target at an angle of 45° with respect to the target surface normal. A dc motor continually rotates the target at about 100 rpm so that each laser shot strikes the fresh surface. Also target can be moved vertically with the help of a vacuum feedthrough that permits to change the laser spot position. The area (7.85×10^{-3} cm^2) of slightly elliptical laser spot on the target surface was inferred by analysis of the crater using optical microscope. A block type NdFeB permanent magnet ($1 \times 1 \times 0.5$ cm^3) was placed behind 2 mm thick tungsten target. Magnetic field at the target surface was 0.23 T, which exponentially decreases along the surface normal and drops down to zero at a distance of about 3 cm. The experiments were conducted in vacuum below 10^{-6} torr to minimize the charge exchange with the ambient residual gas.

The plasma expansion was monitored by a cylindrical IC placed along the target surface normal at a distance of 6.5 cm from the target. The detailed technical diagram of IC is given in Ref. [17]. IC has a circular aperture of 6 mm in diameter. While a grounded aperture of 5 mm diameter was placed before the IC. The IC was biased with -50 V to repel electrons emitted from the laser plasma. The IC signal was determined from the voltage drop across a resistor with the help of a fast digital storage oscilloscope (1 GHz bandwidth).

The charge state distribution of tungsten ions in the far expansion zone was measured by custom-built time-of-flight electrostatic ion energy analyzer (IEA). IC is removed to allow the ions to enter in the field of 45° parallel plate electrostatic IEA. Front plate of IEA is grounded and back plate is at the applied potential V_a. Ions are admitted into IEA through a 2 mm wide slit with some initial energy and charge state, and subsequently decelerated by the constant electric field of $-V_a/d$ between the plates, where d is the distance between the plates. In this configuration, only ions with a particular energy and charge state leave the device through the 2 mm wide exit slit. The ions were detected by means of a Channel Electron Multiplier (CEM) (Model KBL5RS, manufactured by Dr. Sjuts optotechnik GmbH), whose signal was acquired by a fast digital storage oscilloscope (1 GHz bandwidth). A fast photodiode was used to trigger the oscilloscope at the time laser hits the target. The flight distance of ions from target to the CEM was 1.31 m.

3. Results and discussion

The ion collector (IC) spectra measured in time-of-flight configuration at seven different values of the laser fluence without and with application of magnetic field are shown in Fig. 2a & b respectively. For these measurements, laser was incident at an angle of 45° with respect to the target surface normal and IC was placed along the target surface normal at a distance of 6.5 cm from the tungsten target. It can be seen that the ion pulses are fairly broad. The broadness of ion pulses is attributed to the various charge

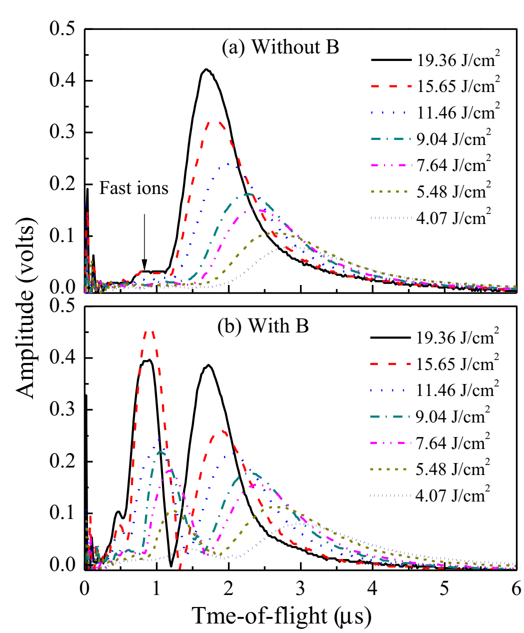

Fig. 2. TOF ion collector spectra recorded at 6.5 cm from the target for various values of the laser fluence, (a) without and (b) with application of magnetic field.

Please cite this article in press as: S.A. Abbasi et al., Highly charged tungsten ions generated by nanosecond pulsed laser and influence of magnetic field on ion charge state, Nucl. Instr. Meth. B (2017), http://dx.doi.org/10.1016/j.nimb.2017.05.050