Vacuum 137 (2017) 14–22

Contents lists available at ScienceDirect

Vacuum

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

Transport line for laser multicharged ion source

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ARTICLE INFO

Article history:
Received 5 September 2016
Received in revised form
5 December 2016
Accepted 7 December 2016
Available online 8 December 2016

Keywords:
Multicharged ions
Transport line
Einzel lens

ABSTRACT

The components of a transport line for a laser multicharged ion source are described. Aluminum and carbon multicharged ions are generated by a Q-switched, nanosecond Nd:YAG laser (wavelength $\lambda = 1064$ nm, pulse width $\tau = 7.4$ ns, and pulse energy up to 82 mJ) ablation of a target in a vacuum chamber. Time-of-flight and a three-grid retarding ion energy analyzers are used to determine the velocity and the charge state of the ions. A three-electrode cylindrical einzel lens is used to focus the ions. At a distance of 30 cm from the center of the focusing electrode of the einzel lens, Al^{1+} and Al^{2+} have a minimum beam diameter of ~1.5 mm, while for Al^{3+} and Al^{4+} the minimum beam diameter is ~2.5 mm. The simulation of the ion trajectories is done using SIMION 8.1. A high voltage pulse applied to a set of two parallel deflecting plates is used for the pickup of ions with different charge states according to their time-of-flight. An electrostatic cylindrical ion deflector is used for analysis and selection of charges with specific energy-to-charge ratio. The design of these transport line components and their operation are described.

1. Introduction

Multicharged ion (MCI) sources are emerging tools for nanoprocessing and nanofabrication [1]. The interaction of MCI with a solid is different from that of the singly-charged ion because the total energy of an MCI depends on the potential energy (charge state) and kinetic energy (velocity). The higher charge state MCI has significant potential energy that is equal to the sum of the ionization energies of stripped electrons. During interaction with a solid, an MCI releases its potential energy along with its kinetic energy. This potential energy causes electronic exchange interaction in the target material and electronic excitation [2]. MCI sources require relatively small acceleration potential because the kinetic energy of the MCIs depends on their charge state. This reduces the requirement on the high voltage power supply making it a comparatively low-cost and compact ion source that can be used for ion implantation. It has been suggested that, because of the ability to control the kinetic and potential energy of the MCIs, the implantation damage by ion recoil can be reduced when using MCIs [3]. For sufficiently slow MCI, the release of this potential energy can be localized on the top few monolayers of the surface and, therefore, can be channeled into the generation of surface nano-features. Surface modification using singly-charged ions may require many particles impinging on the surface site due to a lack of potential energy. The potential energy of the MCI with a high charge state is enough to significantly modify the surface with only a single MCI.

Among the different ion sources, e.g., electron cyclotron resonance ion sources (ECRIS) [4], electron beam ion sources (EBIS) [5], and laser multicharged ions sources (LMCI) [6,7], LMCI can be used for ion production directly from solids. Both ECRIS and EBIS operate only with gases and, therefore, for elements with low vapor pressures, they require introducing gaseous compounds or some vaporization mechanism. LMCI can be used to generate MCIs from any solid, even from nonconductive or refractory targets [7,8]. In LMCI sources, MCIs are generated by focusing a laser pulse on a solid target causing its ablation and ionization. The dense plasma produced consists of ions, electrons, clusters, and neutral particles. The plasma plume expands in a perpendicular direction to the ablated surface. LMCI sources have been tested as potential ion

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http://dx.doi.org/10.1016/j.vacuum.2016.12.009
0042-207X/

sources for ion injection into ion accelerators [9]. Although ions in the LMCI source are produced from a small spot on the target, the plasma plume is directed mainly perpendicular to the target, limiting ion beam divergence. The produced MCIs can be collimated and focused in an ion transport line by einzel lenses. Ion charge state selection can be done by time-of-flight (TOF) pick-up with parallel deflection plates and ions with a narrow range of energy-to-charge ratio can be selected with electrostatic cylindrical deflectors.

Several groups have reported on the design and operation of ion transport line components. For example, a laser ion source utilizing an Nd:YAG ($\lambda = 532$ nm, $\tau = 8$ ns, repetition rate 20 Hz, and maximum laser energy per pulse 30 mJ), Trinczek et al., generated charge state up to Al^{4+} and focused the charges using a three-electrode einzel lens [10]. A pulsed extraction voltage was used to extract and accelerate the ions. The maximum voltage applied for the pulsed extraction and the einzel lens was 30 kV [10]. Yeates et al. reported a laser ion source based on Q-switched Ruby laser ($\lambda = 532$ nm, $\tau = 8$ ns, laser fluence of 0.1–3.9 kJ/cm^2) to generate charge state up to Cu^{6+}. Einzel lenses were utilized to transport and collimate the ion beam, which was detected by a Faraday cup [11]. Nagaya et al. reported on an ECRIS to generate fullerene up to a charge state of C_{60}^{3+}. The transport line consisted of three electrode extraction system, einzel lens, analyzing magnet, slit assembly, and Faraday cup [12].

We previously reported on the development of a LMCI and a spark-coupled LMCI source [13,14]. Here, we discuss the design and operation of transport line components used in the LMCI source. These components are: (1) A time-of-flight (TOF) ion energy analyzer combined with a three-grid retarding field analyzer used to resolve the various charge states and analyze their energy distributions; (2) Three-electrode electrostatic einzel lens used to focus the MCIs; (3) A set of parallel deflection plates used with a pulsed high-voltage source for MCI pick up based on their TOF; and (4) An electrostatic cylindrical deflector ion energy analyzer (EIA) for MCI selection with energy-to-charge E/z ratio. The EIA selects ions according to the E/z ratio from an MCI beam and allows measuring the energy distribution of each charge state. Ion trajectory simulations are done to design transport line components compatible with our experimental conditions and to better understand the operations of the designs. These simulations are carried out utilizing SIMION 8.1 ion optics software [15].

2. Experimental setup

Two LMCI sources are constructed, one is used to produce aluminum MCIs while the other is used for carbon MCIs. The transport line components in both systems are similar. A schematic of the MCI source used for the aluminum source is shown in Fig. 1. A Q-switched Nd:YAG laser pulse (wavelength $\lambda = 1064$ nm, pulse width $\tau = 7.4$ ns at full-width at half maxima (FWHM), pulse energy 82 mJ on target, with maximum repetition rate of 10 Hz) is used to ablate the Al target. An aluminum disc target of area ~1 cm^2, 99.9% purity, 0.5 mm thickness and with a surface roughness (rms) of 261.77 nm, as characterized by the manufacturer (Alfa Aesar), is placed on a multi-axes translational stage. The laser beam is incident on the Al target surface at an angle of $\vartheta = 45°$. A 50 cm focal length convergent lens is used to focus the laser beam on the Al surface. The laser spot area at focus is ~0.0024 cm^2, as measured by the knife-edge method with the edge scanned at 45° to the laser beam. Throughout the experiment, the Al target is biased at 7 kV. The distance from the target to mesh is 10 cm and from the center of the target to the chamber wall is 15 cm. This experimental chamber was described in our recent publications [13,14]. The transport line consists of an einzel lens to focus the ion beam, a pair of deflection plates to select ion charge, a knife edge to measure the ion beam diameter and a Faraday cup (FC) to collect the ions. The distance from the Al target to the center of the middle electrode of the einzel lens is ~94 cm; the knife edge is placed ~30 cm away from the center electrode of the einzel lens. The deflection plates are at a distance of ~120 cm away from the Al target and the FC is at a distance of 33 cm from the deflection plates. The distance from the Al target to the FC is ~153 cm. An EIA can be added before the retarding field MCI analyzer. The EIA allows for the selection of ions with E/z ratio from an ion beam and can also be used to measure the energy distribution of each charge state. The ion energy distribution can also be obtained from the TOF signal.

3. Design and operation of the transport line components

3.1. Faraday cup and three-electrode retarding field analyzer

A time-of-flight energy-to-mass E/m analyzer consists of a drift tube terminated by a Faraday cup (FC) with secondary electron suppressor electrode (SE). A three-grid retarding field ion energy analyzer (RIA) is used to analyze the energy of the MCIs. The FC and the SE are made out of aluminum and have a diameter of 5 cm. The RIA consists of three nickel mesh with a diameter of 5 cm, 100 µm thickness and 70% opening area, separated by 1 cm and placed with the closest mesh to aluminum target at a distance of 143 cm. The outer two electrodes of the RIA are grounded while a variable positive voltage is applied to the center electrode to measure the energy distribution of the ions. The effect of voltage on the RIA was recently discussed [13]. The FC, SE and the retarding field ion

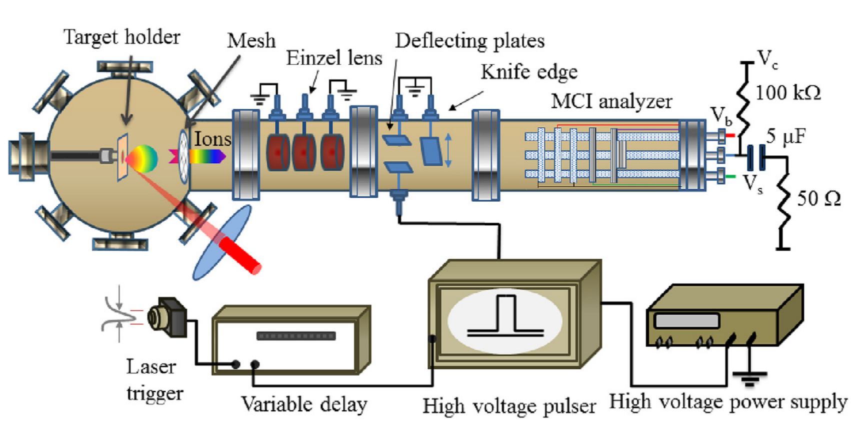

Fig. 1. A schematic of the laser MCI source showing the target chamber, V_c is the Faraday cup voltage, and V_s is the suppressor voltage, and V_b is the barrier voltage.