Production of highly charged argon ions from a room temperature electron beam ion trap*

WANG Tie-Shan(王铁山)[1;1)] PENG Hai-Bo(彭海波)[1] Ovsyannikov V P[3] Kentsch U[3] Ullmann F[3] CHENG Rui(程锐)[1] Zschornack G[2]

1 (School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China)
2 (Technische Universität Dresden, Institute of Applied Physics, Dresden D-01069, Germany)
3 (DREEBIT GmbH, Zur Wetterwarte 50, D-01109 Dresden, Germany)

Abstract In this work, highly charged ions have been extracted from the advanced Electron Beam Ion Source (EBIS-A) developed in a scientific cooperation between the Dresden University of Technology and the DREEBIT GmbH Dresden. The charge state distributions of ions extracted from the EBIS-A are measured in the pulse and leaky modes under different operation conditions. Ar^{16+} ions with current of 2 pA are produced and extracted in the leaky mode. 3×10^5 Ar^{18+} ions per pulse are extracted in the pulse mode. The ion charge state distribution is a function of the ionization time.

Key words EBIS, highly charged ion, ionization time

PACS 52.70.-m, 52.70.Nc

1 Introduction

The studies of highly charged ions (HCIs) have been reported intensively in resent years[1, 2]. Electron Beam Ion Traps (EBIT) or Electron Beam Ion Sources (EBIS) are powerful sources for the production of different kinds of HCIs. The first EBIT was designed by Levine et al.[3] and the bare uranium ions were produced by Marrs et al.[4] In EBIS or Trap, the atoms were injected into the drift tube and ionized into ions immediately. The ions were trapped by a trap configuration formed due to the electron beam potential and an additional electrostatic trap potential. The ionization process happened as a result of successive electron impact ionization in the region of the middle drift tube (see Fig. 1).

The maximum charge states are determined by the ionization factor, which is defined by $j_e\tau$, where j_e is the electron current density and τ is the ionization time. Magnets are used to compress the electron beam up to the densities in the order of 1×10^3 Acm^{-2} to increase j_e. For the cryogenic EBIS/T the high magnetic compression field is produced by the superconducting magnets which need liquid helium or nitrogen for cooling[3—6]. Such systems are very complex and the operation costs to maintain the devices are expensive.

A new type of EBIT or EBIS devices working with permanent magnets were developed in Germany in the cooperation between the Technische Universität Dresden and the DREEBIT GmbH Dresden[7]. These ions sources are commercially available now[7] and open a new access to use highly charged ions in basic research for technological applications. The ion sources are very compact facilities without any cryogenic liquids. Compared with the cryogenic EBITs, the Dresden EBIT or EBIS are much simpler, smaller, cheaper and more reliable[8—11]. A schematic sketch of the Micro-Beam Facility of the TU Dresden is shown in Fig. 2. All measurements reported in this paper are realized at the facility.

2 Experimental setup

The principle of operation of Dresden EBIS or Trap is shown in Fig. 1 and Fig. 2. The electrons emitted from cathode are accelerated by an electrostatic field between the cathode and the drift tube

Received 19 July 2007
* Supported by National Natural Science Foundation of China (10475035)
1) E-mail: tswang@lzu.edu.cn

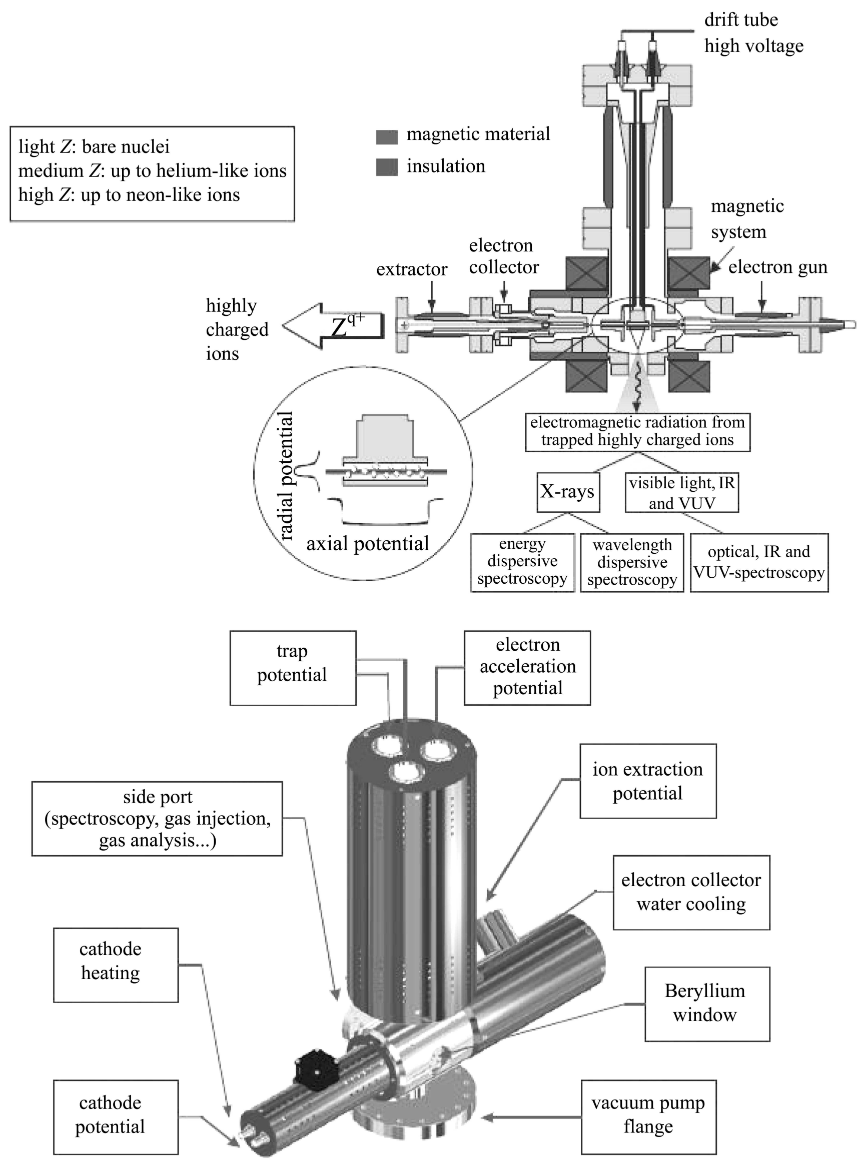

Fig. 1. Principle of operation (top) and operational scheme (bottom) of the Dresden EBIS.

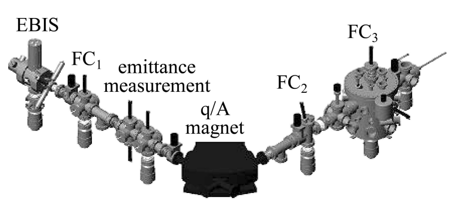

Fig. 2. Schematic of the ion beam line of the Micro-Beam Facility of the TU Dresden. FC-Faraday cup.

ensemble. While the electrons are passing though the drift tube region, the ions are ionized by the collision of electrons in a high dense electron beam. The electron beam is compressed by permanent magnets which produce a magnetic field of about 600 mT. After passing the third drift tube, the electrons are decelerated to 3 keV and more than 99.8% of the electrons are collected by a water-cooled collector[12]. The ions which are trapped by the electron beam and the electrostatic potential wall are further ionized and heated by the elastic electron-ion collision. After trapped certain time, the ions are extracted at different extractor voltages. Passing though the ion-optical components (einzel lens and deflectors), the ions are separated by an analyzing magnet. Then the charge state separated ion beam is detected by a Faraday cup. The Faraday cup is connected with the electrometer which can measure the current down to fC in Coulomb mode. There is a cable outside the electrometer to avoid disturbance. The complete ion beam-line works under ultra high vacuum conditions (in the order of 10^{-9} mbar) and is controlled by computer.

3 Results and discussion

3.1 Charge state distribution

Principally there are two modes for extracting ions from the ion trap: the leaky mode and the pulsed mode. The trap potential is kept to be constant in leaky mode. The ions with high enough kinetic energy can overflow the wall and escape. In the pulsed mode, the trap potential opens periodically with an adjusted frequency. Fig. 3 and Fig. 4 show the ion charge state distributions of argon ions which are extracted from the Dresden EBIS-A. In the experiment, the current of Ar^{16+} ions in the leaky mode is 2pA at an electron current of 64 mA and an electron energy of 18 keV. The argon working gas pressure is 3×10^{-9} mbar and the trap potential is 80 V. As one can see in Fig. 4, about 1×10^5 Ar^{17+} and 3×10^5 Ar^{18+} ions per pulse are extracted from the EBIS-A with the ionization time of 0.3 s and 5 s, respectively. The electron energy is 13.5 keV, the electron current is 77 mA, the argon pressure is 3×10^{-9} mbar, the trap potential is 100 V and the extracted time is 10 ms.

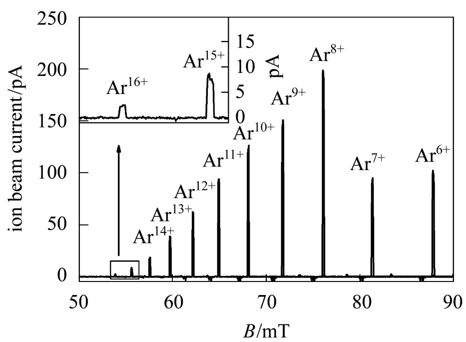

Fig. 3. Charge state distribution of Ar ions extracted from the Dresden EBIS-A in the leaky mode.

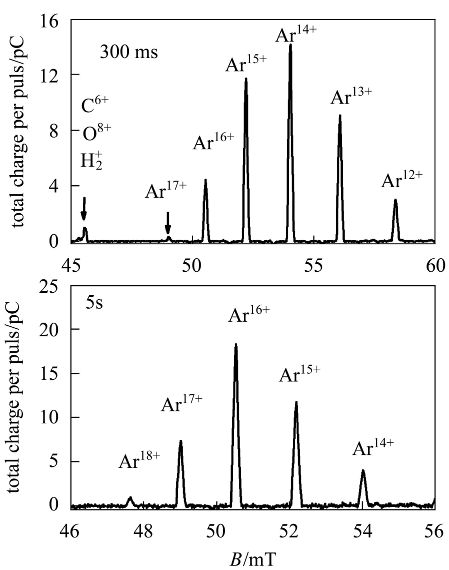

Fig. 4. Spectrum of argon ions extracted from the Dresden EBIS-A in the pulse mode.

3.2 Time development of the argon charge state distribution

The development of individual ion charge states versus the ionization time is shown in Fig. 5. It can be seen from this figure that the ions are extracted in the pulse mode with an electron energy of 13.5 keV and an electron current of 77 mA, respectively. The source pressure is 3×10^{-9} mbar and the depth of the trap is 100 V. Ar^{17+} and Ar^{18+} ions are produced with the ionization time of 200 ms and 600 ms, respectively. The mean charge state increases with increasing of the ionization time. The ions intensity of Ar^{12+}, Ar^{13+} and Ar^{14+} goes up to the maximum and then decreases as the ionization time increases.

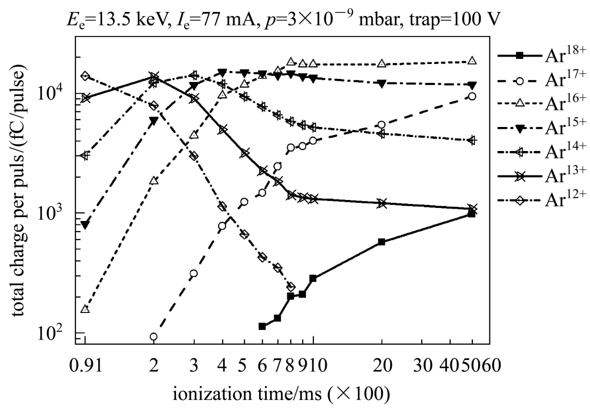

Fig. 5. Dependence of the ion charge state distribution of argon ions on the ionization time with an electron energy of 13.5 keV. The ions were extracted from the EBIS-A in the pulsed mode.

The distribution of charge state in the EBIS-A would pass two steps. In the first step the atoms are ionized and heated by electrons and the multi charged ions (MCIs) are accumulated in the trap. The mean temperature of MCIs is low and only a few ions can escape from the potential wall. In the second step HCIs are produced with the increase of ionization time. The temperature of HCIs is higher than that of the MCIs under the same working conditions[13, 14]. The collision between ions become more important than the electron heating and then MCIs are heated deeply by HCIs. The temperature of MCIs in the second step is higher than that in the first step. As a result, MCIs could easily overcome the potential wall, and the density of MCI in the drift tube is decreased.

Figure 6 shows the dependence of output of the extracted ions on the trap potential. Here the electron energy is 13.5 keV and the source pressure is about 3×10^{-9} mbar. The relative intensity is defined by I_{q+}/I_e, I_{q+} is the ion current extracted from EBIS and I_e is the electron current, respectively. The relative ion output goes up to the maximum at trap potential of 60 V and then drops dramatically with the increase of trap potential. One can conclude that the trap potential should be kept below 80 V at an argon pressure of 3×10^{-9} mbar[12]. The trap potential has great influence on the output current of highly charged ions in leaky mode because only the ions, which have high enough temperature, can overcome and escape the barrier. The higher the ion temperature in EBIT is, the larger the ion output would be in leaky mode. In leaky mode the application of heavier atoms should lead to an increase of the ion temperature in the EBIT.

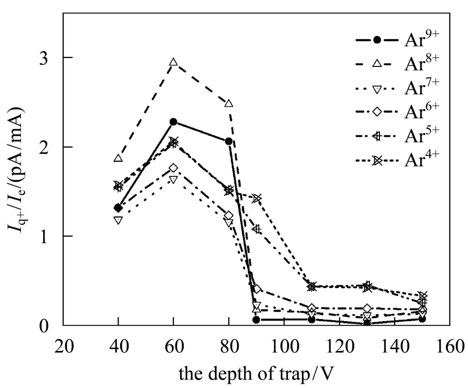

Fig. 6. Dependence of the extracted currents of individual ion charge states on the trap potential.

4 Conclusions

The Dresden EBIT or EBIS are useful devices to produce HCIs. Here one of these sources, the Dresden EBIS-A is analyzed. Compared with the cryogenic EBITs the Dresden EBIS-A is more compact, reliable and economical. The ion charge state distributions extracted from the Dresden EBIS-A are measured under different operation conditions. In the leaky mode the Ar^{16+}ions are produced and extracted at an electron energy of 18 keV and an electron beam current of 64 mA at an working gas pressure of 3×10^{-9} mbar. The time development of individual ion charge states has been measured by ion extraction experiments. Here about 3×10^5 Ar^{18+} ions are extracted per pulse at an electron energy of 13.5 keV and an electron beam current of 77 mA without additional coolants. The result suggests that the trap potential has significantly influence on the output of highly charged ions in the leaky mode.

This work is supported by the Forschungszentrum Dresden-Rossendorf. One of the authors (H.P.) would like to thank Prof. W. Moeller for supporting his stay in the Forschunszentrum Dresden-Rossendorf. The authors would like to thank K. Arndt and R. Heller for their technical support. and Ding Da-Jie and Yang Xiu-Yu for their exciting discussions.

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