Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Experimental Studies of Ar^{n+} ionization using an EBIS

Seunghyun Lee*, Han-Sung Kim, Hyeok-Jung Kwon, Yong-Sub Cho
Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju, Korea
**Corresponding author: shl@kaeri.re.kr*

1. Introduction

Electron beam ion source (EBIS) has been one of widely used table-top devices for the production of highly charged ions by electron impact ionization. EBIS employs a magnetically compressed, high energy and density electron beam to sequentially ionize atoms or ions in a low charge state.

Combination of an EBIS and a Radio frequency quadrupole (RFQ) is a suitable means of heavy ion beam production at low energies. With EBIS, beams of any element can be prepared including uranium and spin-polarized ^{3}He with a narrow charge distribution. It has demonstrated its reliability and flexibility as a pre-injector used at several accelerators and collider facilities such as Brookhaven National Laboratory, Relative Heavy Ion Collider, NASA Space Radiation Laboratory, Argonne National Laboratory and Large Hadron Collider [1, 2, 3].

At Korea Multi-purpose Accelerator Complex (KOMAC), we have a compact EBIS, operated at room temperature. It is additionally constructed with a dipole bending magnet and a Faraday Cup to separate the charge distribution and measure charge spectra of an ion beam from the EBIS. Using this setup, helium (He) and argon (Ar) gases have been tested to produce charge spectra. Here, we present our detailed study of Ar ion spectra in various electron beam conditions to understand charge changing reactions of Ar and space charge effect of electron beam.

2. Methods and Results

Ion-neutral processes in the EBIS can be largely divided into three; charge changing reactions, energy dynamics and ion spatial distributions [4]. They are related with electron current density and electron energy, and also related to each other. In this paper, we show some of our results based on charge changing reactions and energy dynamics of Ar ions in the EBIS. First, we go through our experimental setup. Then few results of Ar ions are shown.

2.1 Experimental setup

Fig. 1 shows an experimental setup of an EBIS at KOMAC, consisting of a commercially available EBIS (Dreebit GmbH), a dipole magnet and a Faraday cup. The EBIS operates with an electron gun, a strong permanent magnetic coil and three drift tubes. The electron gun in the EBIS produces a highly emissive electron beam for the ionization. The magnetic coil compresses the electron beam to increase the density of electrons, which improves the efficiency of the ionization. Ions are produced by electron impact ionization. Then, these ions are confined radially by negative space charge of the electron beam and axially by electrostatic potential formed by three drift tubes. The ions of various charge states and masses are produced in the EBIS. To characterize the extracted ion beam from the ion source, we employ the dipole bending magnet to separate the ions depending on their charge states and masses. It is a bending magnet with a focal length of 1.28 m, deflecting only a certain mass-to-charge ratio at 90˚. Magnetic field strength, **B** is varied by changing current in the coil. For detection, we place a slit in front of the Faraday cup to filter out and improve an ion signal. Output of the Faraday cup is connected to a current preamplifier to enlarge the ion signal. First, Ar ion spectrum is obtained. The ion peaks are identified till n = 16.

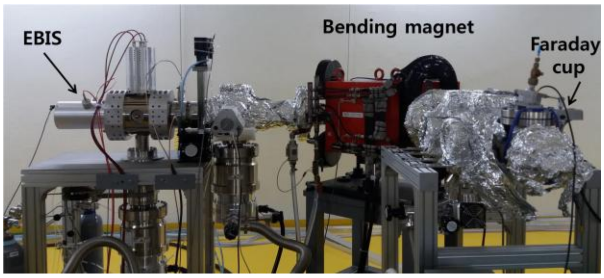

Fig. 1. Picture of the experimental setup: It consists of an EBIS, a bending magnet and a Faraday cup.

2.2 Charge Changing Reaction

The electron impact ionization is the most fundamental ionization process in the ion source physics. The cross section for the impact ionization is by orders of magnitude higher than other ionization channels. Moreover, in the electron impact ionization, single ionization cross section is about one order of magnitude or more higher than double ionization process. In our case, we only consider successive ionization processes to produce multiply charged ions.

Using the Mosley’s law in transitions from the continuum to the K-shell, we can approximately calculate the ionization energy (E_i), cross section (σ) and the ionization time factor ($j_e \tau$) from (Z-1) to Z for the production of multiply charged ions from H-like ions. The calculation for the argon is shown in the Table I. This approximation is not so powerful in lowly charged ions but yet useful in the experiments. For a given electron current density, the required ionization time for Ar^{n+} is roughly set. To understand the process in the simplest way, we measure Ar^{1+} and Ar^{2+} ion signals at various electron currents, as shown in Fig. 2. The slope gives the ionization factor and we compare our result with the estimate values.

Table I: Ar ionization

Z	**E_i (eV)**	**σ(cm^2)**	**$j_e\tau$ (e^- ms)**
1	13.6	8.95×10^{-17}	1.8
2	54.4	5.59×10^{-18}	28.6
3	122	1.10×10^{-18}	145
4	220	3.50×10^{-19}	460
5	340	1.43×10^{-19}	1120
6	490	6.91×10^{-20}	2300
7	666	3.73×10^{-20}	4300
8	870	2.19×10^{-20}	7300
9	1100	1.36×10^{-20}	11700
10	1360	8.95×10^{-21}	18000
11	1646	6.11×10^{-21}	26200
12	1958	4.32×10^{-21}	37100
13	2300	3.13×10^{-21}	51000
14	2665	2.33×10^{-21}	68800
15	3060	1.77×10^{-21}	90000
16	3482	1.37×10^{-21}	117300
17	3930	1.07×10^{-21}	155000
18	4400	8.53×10^{-22}	188000

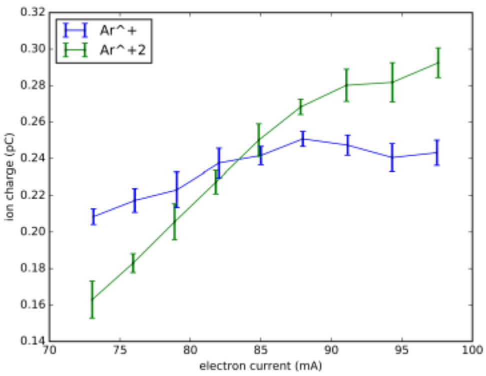

Fig. 2. Plot of Ar^{1+} (blue) and Ar^{2+} (green) ion signals at various electron currents.

2.3 Space Charge effect of the electron beam

Electron beam modifies net electron energy due to its space charge potential [5]. The space charge potential decreases the final electron beam energy. The central kinetic energy of output ion signals at various electron currents is evaluated from a Gaussian fit of the data. From the fit, we estimated the space charge effect of our EBIS system.

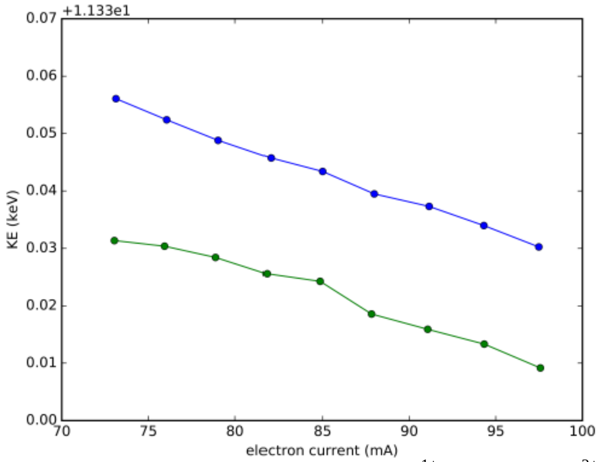

Fig. 3. Plot of central kinetic energy of Ar^{1+} (blue) and Ar^{2+} (green) ion signals at various electron currents.

3. Conclusions

An EBIS is employed to produce ions in multiply charged states. We measure an Ar ion spectrum and identify it till 16th charge state. A detailed experimental study of Ar^{1+} and Ar^{2+} ions is performed to characterize the effects of electron beam for ionization.

REFERENCES

[1] M. Okamura *et al.*, "Beam Commissioning of the RFQ for the RHIC-EBIS Project", in *Proc. PAC'09*, Vancouver, BC, Canada, FR5REP046.

[2] J. Alessi *et al.*, "Construction of the BNL EBIS Preinjector", in *Proc. PAC'09*, Vancouver, BC, Canada, MO6RFP025.

[3] B. Mustapha *et al.*, "Simultaneous Acceleration of Radioactive and Stable Beams in the Atlas Linac", in *Proc. HB2014*, East-Lansing, MI, USA.

[4] F. Currell and G. Fussmann, "Physics of Electron Beam Ion Traps and Sources", IEEE TRANSACTION ON PLASMA SCIENCE, Vol 44, No. 6, 2005

[5] G. Zchornack, M. Schmidt and A. Thorn, "Electron Beam Ion Sources", arXiv:1410.8014v1, 2014