Present status of slow highly charged ion facility at RIKEN

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To study collision processes of slow and ultra-slow highly charged ions (HCI) with atoms, molecules, and surfaces, we have been constructing a slow highly charged ion facility at RIKEN. A 14.5 GHz Caprice type ECR ion source (ECRIS) is used as the primary ion source of the facility. At present, the energy of the ion beam from the ECRIS ranges from 10 eV/q to 20 keV/q, where q is the charge state of the ions. This paper presents the overview of the present facility

Introduction

Collision processes of slow highly charged ions (HCI) with atoms, molecules, and surfaces have been intensively studied in the last decade.[1,2)] "Slow" referred above means collision velocities smaller than the velocity of active electrons participating the collision. At this energy region, precise measurements have been done with various experimental techniques.[2–7)] When the collision energy becomes even lower, the collision processes of HCI with atoms, molecules, and surfaces are expected to show qualitatively different features such as:

(1) The Langevin orbiting processes due to an induced dipole polarization become predominant in charge transfer processes. The Langevin cross section is given by $\sigma_L = \pi[4\alpha q^2/\mu v^2]^{1/2}$, where α is the dipole polarizability of the target, q the charge state of the projectile ion and v the collision velocity, μ the reduced mass of the collision system. Since the Langevin cross section is proportional to q/v, this effect enhances the charge transfer cross section at low energies($< 1\,\text{eV}/q$) in the HCI collisions.[7)]

(2) In ion-solid interaction, one of the most important parameter is the energy deposition, which is normally governed by the kinetic energy (K) of the projectile. In the case of slow HCIs, their potential energy (U) is expected to play an important role. A zeroth order criteria of the potential energy dominant region may naturally be given by $U > K$, where the effect of the potential energy governs various processes.[8–10)]

In order to study such new frontier of the HCI collisions with mono-energetic and ultra low energy HCI beams, we have been constructing a slow highly charged ion facility at RIKEN. The HCI beams in the energy range from 10 eV/q to 20 keV/q has already been used for experiments. New parts of the facility to produce ultra slow/cold HCIs are now under construction.

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Overview of the facility

Layout of the facility is shown in Fig. 1. The facility consists of three parts:

1: A 14.5 GHz Electron Cyclotron Resonance Ion Source (ECRIS) and four slow HCI beam lines.

2: An electro-magnetic trap for the production of ultra slow HCIs.

3: A fs TW laser to produce HCIs.

The 14.5 GHz Caprice type ECRIS is used as the primary ion source. Specifications of the ECRIS are shown in Table 1. We have used three kinds of plasma chamber, (1) a double wall stainless steel(SUS) plasma chamber, (2) a double wall stainless steel plasma chamber with a 1 mm thick aluminum sheet, and (3) a single wall aluminum (Al) chamber. Typical ion currents for each plasma chamber, which are measured after an analyzing magnet(AM), are shown in Fig. 2. The data indicate that increasing the area of Al surface in the plasma chamber, the fractions of higher charge states increase. This is due to the increase of the secondary electron production

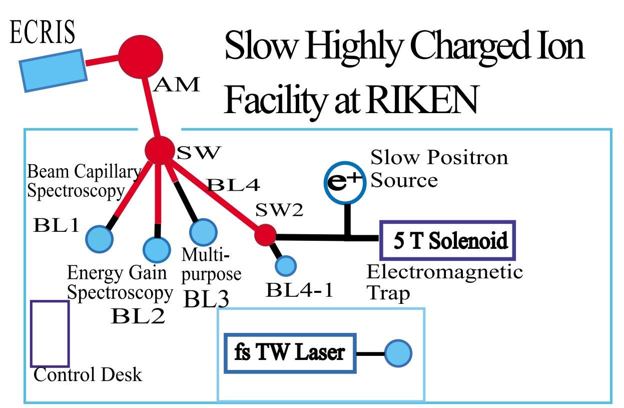

Fig. 1. Layout of the facility. HCI beams from the ECRIS are delivered to three experimental setups(BL1 to 3) and to the HCI trap(BL4). AM: analyzing magnet, SW, SW2: switching magnet. The BL4-1 is now under preparation for the BCS experiment. AM, SW, SW2, and beam lines indicated by read color can be floated.

Table 1. Specifications of the ECRIS.

Maximum magnetic field	1.3 T
Material of Hexapole magnet	NdFeB
Magnetic field of Hexapole	1.04 T (single wall chamber)
	1.0 T (double wall chamber)
RF frequency	14.5 GHz
RF power	< 1.3 kW
Inner Diameter of plasma chamber	66 mm (single wall chamber)
	62 mm (double wall chamber)
Extraction voltage	< 20 kV

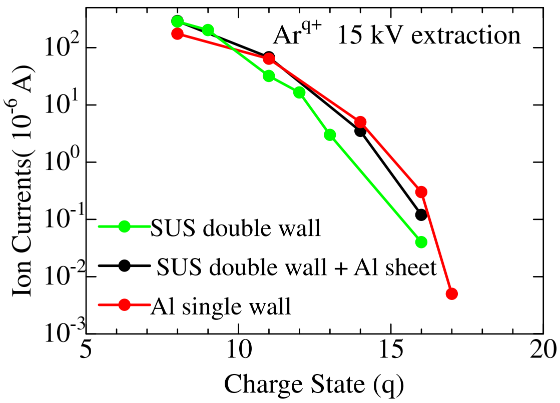

Fig. 2. Argon ion currents from the ECRIS measured after AM with different plasma chamber. Extraction voltage is 15 keV. Beam size at Faraday cup is 18 mm × 18 mm. Green, black, and red circles are for the SUS double wall chamber, the SUS double wall chamber with the Al sheet, and the Al single wall chamber, respectively.

efficiency in the plasma chamber.

The HCI beam is extracted from the ECRIS and momentum-analyzed by the analyzing magnet. The HCI beam is then focused by a magnetic quadrupole triplet lens and delivered to one of the four beam lines by a switching magnet (SW). The beam line from the extraction part to just before the experimental setups can be floated (< 5 kV) in order to transfer slow HCIs (> 10 eV/q) with high efficiency. The power supplies for the beam line are set on a floated stage and are remote controlled from a control desk in Fig. 1 with an optical fiber.

The BL 1 is for a soft X-ray beam-capillary spectroscopy (BCS)[11–13] of meta-stable states. The HCIs are transported through the floated beam line, which are then decelerated and focused by an electrostatic lens system just in front of the capillary. In this case, the energy spread of the beam is determined by the intrinsic energy width of the ions from the ECRIS, which is typically a few eV/q. Available energy range at the BL1 is from 10 eV/q to 20 keV/q. Detail of the experiment at the BL1 will be explained in other paper in this issue.[14]

The BL2 is for experiments with mono-energetic slow HCIs. It consists of a deceleration lens followed by a double path hemispherical analyzer of 40 mm in radius as shown in Fig. 3. The deceleration lens consists of 6 disk electrodes with 40 mm inner diameter, which works as a highly-efficient first

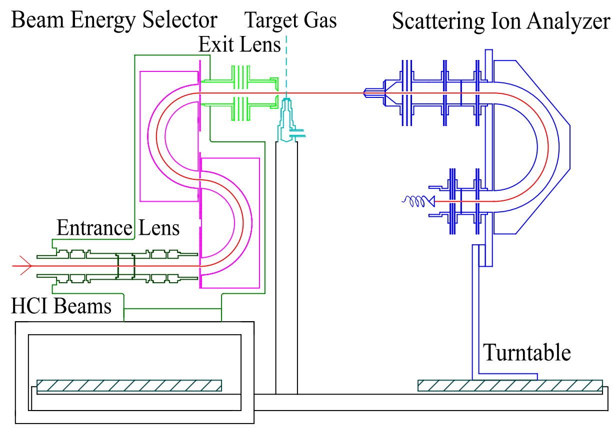

Fig. 3. Energy selector and scattering ion energy analyzer at the BL2. Decelerated HCIs are energy selected and collide with the gas target. After the collisions, the energy and scattering angle of the HCIs are measured by the scattering ion energy analyzer.

deceleration stage of HCIs from 2–5 keV/q down to 300 eV/q. The 300 eV/q HCIs are further decelerated by a second deceleration lens down to the final energy, which are then monochromatized with the double path hemispherical analyzer having an energy resolution of $\Delta E/E = 1/150$.[15,16] Four jaw slits, which are set between the two deceleration stages and are not shown in Fig. 3, and two collimators of 1 mm diameters at the entrance lens of the hemispherical analyzer are used to limit the angular divergence to about 1degree. Typical currents after the analyzer are listed in Table. 2. A single-path 50 mm radius hemispherical electrostatic energy analyzer with $\Delta E/E = 1/100$ is installed on a turntable in the chamber as shown in Fig. 3, which allows to make double differential energy gain spectroscopy. Available energy range at the BL2 is from 10 eV/q to 300 eV/q.

Table 2. Typical ion currents below 100 eV/q at the BL2. High voltage −2 kV is applied to the beam line. The ion intensities are measured after the deceleration and energy analysis. Typical beam size at the Faraday cup is a few mm.

Ions	Ar^{4+}	Ar^{6+}	Ar^{8+}	He^{+}	He^{2+}
Energy(eV)	240	270	280	20	140
Energy Width(eV)	2.7	1.5	1.6	0.18	1.16
Intensity(10^8 s^{-1})	8.4	7.5	1.4	0.4	15.6

The BL3 is a plain (*i.e.* no deceleration mechanism) beam line for various ad hoc experiments.[17] The available energy of HCIs is from 1 keV/q to 20 keV/q.

The BL4 is newly prepared particularly for a preparation of ultra slow HCIs. The HCIs from the ECRIS are transported to an electro-magnetic trap through the BL4 and a second switching magnet (SW2). Available energy at the BL4 is from 1 keV/q to 20 keV/q. The HCIs injected into the trap are sympathetically cooled with cold positron plasmas pre-injected in the trap. Detail of the cooling scheme in the trap will be described in other papers.[18–20] At BL4-1 which is another beam line after SW2, a visible light BCS experiment is under preparation which will provide information on the very beginning of the charge transfer in HCI-surface collisions.[13,21]

In parallel to the production of positron-cooled ultra slow HCIs, a fs TW laser is prepared (see Fig. 1) to study the production mechanisms of HCIs under strong electric field, which is known to induce multiple ionizations on atoms, molecules, and clusters.[22–25] Detail of the TW laser system will be explained in other paper in this issue.[26]

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