Journal of the Korean Physical Society, Vol. 32, No. 3, March 1998, pp. 353∼355

Atomic Physics Experiments Using the Tokyo Electron Beam Ion Trap

Shunsuke Ohtani and Nobuyuki Nakamura

Institute for Laser Science, University of Electro-Communications, Chofu, Tokyo 182-8585, Japan
and
Cold Trapped Ions Project, ICORP, JST, Chofu, Tokyo 182-0024, Japan

(Received 20 June 1997)

A new electron-beam ion trap (EBIT) has been constructed at the Institute for Laser Science, University of Electro-Communications. The general features of the Tokyo EBIT, as well as its design and operation, are given. During the first test phase, X-ray spectra from Ne-like Ba and W ions and also from bare and hydrogen-like Kr ions were observed. This paper also shows the propsed experimental program.

I. INTRODUCTION

The newly constructed electron beam ion trap (EBIT) in Tokyo is intended mainly for spectroscopic observations of highly charged ions (HCIs) through electron-ion reactions in the Trap. In the last decade, precise spectroscopic investigations of HCIs have become feasible [1] in which HCIs can be produced by successive electron impact but with a shorter trap length to limit two-stream instabilities in the trap region, hence making the trapping time longer. The long trapping time is important not only for producing HCIs but also for performing precise spectroscopic studies. Important improvements in EBIT operations have been made by a group at Lawrence Livermore National Laboratory (LLNL) [2] for more than ten years. Recently, similar devices have been installed at Oxford [3], NIST [4], and Berlin [5].

The new EBIT in Tokyo has many features which differ from other EBITs although the basic concepts for the production and the trapping of HCIs and the same. In this paper, we present the general features of our device and its operation, the results of recent observations with the Tokyo EBIT, and also our planned experimental program.

II. THE DEVICE

A detailed description of the design is given in Refs. 6 and 7. Here, a brief description of the unique features is given. The EBIT consists of thres parts, an electron gun, a cryostat region including drift tubes, and an electron collector. Both the gun and the collector are designed to be floated at −100 kV in air and at up to −300 kV from the earth potential in SF_6 gas. The drift tube in which HCIs is produced and floated at up to +40 kV from the earth potential. Then, it is possible to generate an electron beam with an interaction energy of up to 340 keV in the drift tubes. An overview of the Tokyo EBIT is shown in Fig. 1.

Electrons are emitted thermionically from a spherically shaped dispenser-type cathode which is 3 mm in diameter and which can emit a 300 mA electron beam at an anode voltage of 8 kV. After a number of computer simulations of the electron trajectories, we determined the shapes of the electrodes and the electric- and the magnetic-field distributions in the region of the electron gun.

The drift tubes generally consist of three electrodes. At the center electrode, HCIs are trapped and interact with an electron beam. Furthermore, the center region is designed to be a cylindrical Penning trap structure in order to observe the ion motions. Normally, the superconducting magnet vessel is at 4.2 K and acts as a cryopump. Using the Joule-Thomson adiabatic expansion method, the temperature of liquid helium can be decreased to below 2.4 K. The vapor pressure of H_2, which is considered to be the dominant residual gas under an ultra-high vacuum condition, is about 10^{-6} Torr at 4.2 K and about 10^{-15} Torr at 2.4 K; hence, the vacuum of the trap region is expected to be significantly improved. Eight observation ports are situated around the trap to facilitate spectroscopy, beam diagnostics, and gas injection.

III. THE FIRST TEST OPERATION

In the first test phase, the maximum electron current was 200 mA at 80 keV with a magnetic field of 4.5 T. A rough determination of the beam radius was done by observing the beam image with a visible CCD camera.

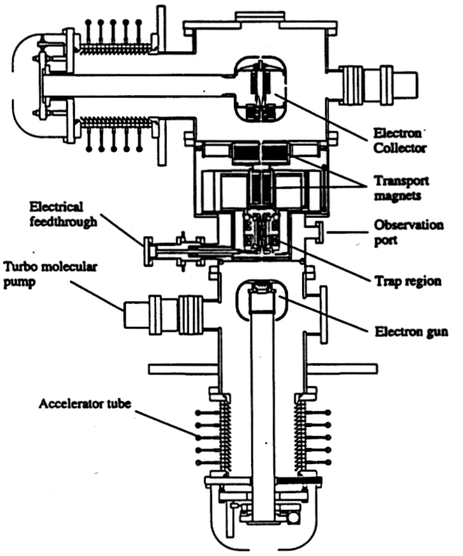

Fig. 1. An overview of the Tokyo EBIT.

The beam diameters were estimated to be less than 200 μm, depending on the operation conditions. A typical visible image of the electron beam is shown in Fig. 2.

A typical X-ray spectrum observed with a Si(Li) detector is shown in Fig. 3 for the case of no injection of ions or neutrals from the outside into the trap region. It can be seen that Ne-like W^{64+} and Ba^{54+} are trapped and emit X-ray through interactions with high-energy electrons. Tungsten and barium are contained in the cathode materials. Those atoms are sputtered from the cathode by the ion feedback process. They drift along the beam axis to eventually become ionized and trapped

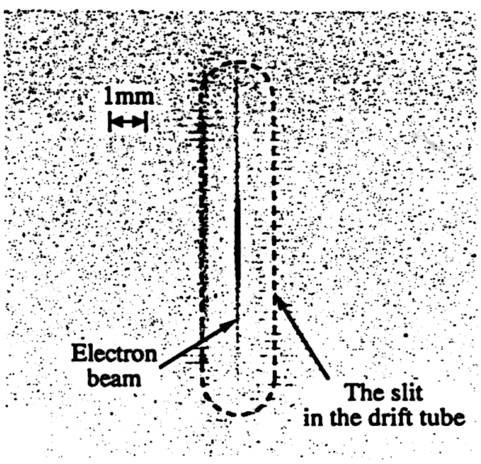

Fig. 2. A visible image of an electron beam with an energy of 20 keV and a current of 150 mA. An Xe-gas beam is injected into the center of the drift tube.

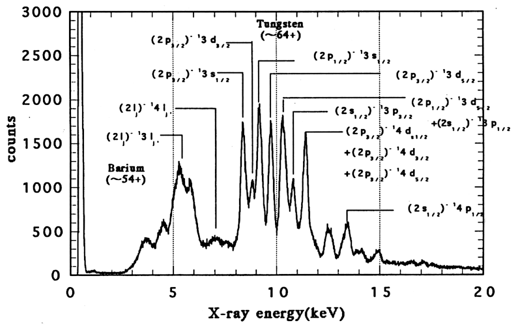

Fig. 3. X-ray spectrum of Ba and W ions: E_{beam}=19.9 keV and I_{beam}=100 mA.

in the trap.

When a gas is injected into the trap, the X-ray signals emitted from the injected element become dominant. In Fig. 4, an X-ray spectrum observed with a pure Ge detector is shown for the case of Kr-gas injection. Large X-ray signals from low-charge-state Kr ions are observed in the spectrum. Furthermore, in the highest X-ray energy region at 45 keV, there are two peaks due to radiative recombination (RR) processes into the n=1 shell, and these provide clear evidence for the production and the trapping of bare and hydrogen-like Kr ions.

IV. THE PROPOSED EXPERIMENTS

Various experiments are planned for the Tokyo EBIT. These include

(1) measurements of the 1s Lamb shift in hydrogen-like ions of high-Z elements by observing free-bound transitions with high-accuracy and high-resolution X-ray spectroscopy,

(2) systematic observations of dielectronic recombination processes for high-Z ions,

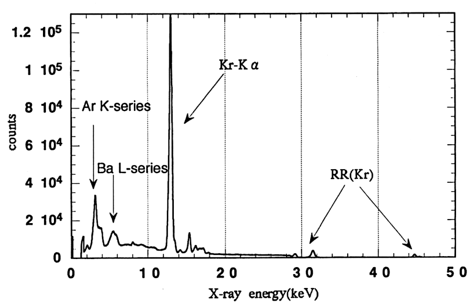

Fig. 4. X-ray spectrum of Kr ions : E_{beam}=27.7 keV and I_{beam}=110 mA. Radiative recombination (RR) lines to n=1 shells of bare and H-like Kr ions are observed at around 31.5 keV. Ar ions act as a coolant in an evaporative cooling process.

(3) observations of hyperfine structures in hydrogen-like ions of high-Z elements by visible spectroscopy and laser-induced fluorescence spectroscopy,

(4) investigations of visible and VUV transitions in high-Z ions, and

(5) observations of nuclear processes, such as bound-state β-decay processes, for special high-Z HCIs.

ACKNOWLEDGMENTS

The author is grateful for the Grant-in-Aid for Scientific Research on the Priority Area, "Atomic Physics of Highly Charged Ions" from the Ministry of Education, Science and Culture. The design, construction and operation of the Tokyo EBIT have been performed in collaboration with several colleagues and students, although the names are not described in this paper.

REFERENCES

[1] E. D. Donets and V. P. Ovsyannikov, JETP **53**, 466 (1981).
[2] R. E. Marrs, M. A. Levine, D. A. Knapp and J. R. Henderson, Phys. Rev. Lett. **60**, 1715 (1988).
[3] H. S. Margolis, A. J. Varney, R. A. Jarjis and J. D. Silver, Nucl. Instr. Meth. **B98**, 562 (1995).
[4] J. D. Gillaspy *et al.*, Physica Scripta **T59**, 392 (1995).
[5] Ch. Biedermann, A. Förster, G. Fußmann and R. Radtke, Physica Scripta **T73**, 360 (1997).
[6] F. J. Currell *et al.*, J. Phys. Soc. Japan **65**, 3186 (1996).
[7] For example, N. Nakamura, Physica Scripta **T73**, 362 (1997).