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The SPARC EBIT at GSI; Commissioning and Future Plans at the HITRAP Beamline

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Abstract. This contribution describes the current set-up and future plans for a small permanent magnet electron beam ion trap (EBIT) which has been installed at GSI. The EBIT is planned to serve as an off-line test ion source for experiments on the HITRAP project and also as a test-bed for instrumentation under development for the SPARC collaboration which is part of the new FAIR facility to be built at GSI. In order to increase the range of highly charged ion species which are produced by the source a charge breeding program has been initiated in which singly charged ions are externally injected into the EBIT with high efficiency. We describe recent results from the initial conditioning of the EBIT along with preliminary results of charge breeding tests.

1. Introduction
A small permanent magnet EBIT (Dresden EBIT \cite{1, 2}) has been installed at GSI to serve as an off-line test ion source for the HITRAP project \cite{3} and for use as a test setup for charge breeding explorations. The EBIT is named ‘SPARC EBIT’ as it will also be used as a test facility for instrumentation under development for the SPARC collaboration \cite{4}. We describe some results of the initial conditioning of this source.

The characterisation of the EBIT is divided into two main areas; 1. x-ray measurements of the photons emitted from the trap, giving information on the charge state balance in the trap (section 3.1) and 2. measuring the composition of charge states in the ion beam extracted from the EBIT (section 3.2).

Since it is planned to use the EBIT as test source for HITRAP experiments charge breeding and efficient extraction from the EBIT is being investigated. Charge breeding involves the injection of atoms or low charge states into the EBIT and then extracting the HCI for use in another experiment.
2. Current Setup

The current status of the SPARC EBIT beamline is shown in figure 1. The EBIT is in the right hand side of the figure with ions extracted to the left and directed towards a quadrupole bender. The Dresden EBIT device has been described in detail elsewhere. Essentially it consists of a highly emissive Ir-alloy cathode which is biased up to -3 kV delivering a focussed electron beam of up to 50 mA. This beam is compressed by the magnetic field generated from a pair of SmCO permanent magnet rings placed inside the vacuum chamber. These magnets surround a cylindrically trap region and provide a maximum field of 250 mT at the centre of the trap. The trap region consists of 3 electrodes, by biasing the outer electrodes positively with respect to the center electrode, ions may be trapped in the central region. The compressed electron beam passes through the center of the trap interacting with the trapped ion plasma to create highly charged ions by successive ionization.

![Figure 1. The current EBIT beamline](image)

The trap electrodes may be biased positively up to a potential of 12 kV providing a total maximum electron beam energy of 15 keV. The power supply connected to the third trap electrode is controlled by a fast switching device allowing this supply to switch between two pre-determined voltages very rapidly. This set-up is used to switch on and off the axial trapping by switching the potential of this electrode from a value above the centre electrode, i.e. trap closed, to one equal to or slightly below the centre electrode, i.e. trap open. When the trap is opened the ion cloud is directed towards the extraction region and can be extracted into the connecting beamline.

The first part of the beam line consists of several focussing and deflection elements and a diagnostic chamber which is described in more detail later. A large multi-pass spectrometer (MPS) magnet is positioned in the central part of the beamline allowing the beam to be directed either 90° to the left, straight ahead or 90° to the right. The beamline to the left of the magnet contains a MCP detector which allows the charge balance of the beam to be determined by varying the current in the magnet and scanning the beam across the detector. When the ions are undeflected they are directed towards a time of flight (TOF) analysis chamber. By deflecting the beam 90° to the right the ions are directed towards a magnesium target. This
target consists of a Mg oven which produces a thin beam of Mg atoms which traverses the ion beam perpendicularly from above. It is planned in the future to perform ion-atom collision experiments using this apparatus.

In the current setup singly charged alkali ions (e.g. K) are externally injected from a thermionic aluminosilicate ion source supplied by HeatWave Labs Inc. These ions are then deflected through 90° by a quadrupole bender and subsequently trapped in the EBIT and ionized. Simulations of ion injection into and extraction from the trap region have been performed using SIMION [5] which suggest that charge breeding is feasible. Expected yields of HCI can also be estimated using simulation codes which model the charge state evolution in the trap [6].

3. Results
3.1. X-Ray Spectra
The Dresden EBIT is equipped with two windows providing line of sight to the trap region at 90° to the electron beam. We have used one of these windows to observe the x-rays emitted from interactions between HCI and electrons inside the trap region. An Amptek XR-100CR Si-pin diode detector was used for these measurements. This detector has a surface area of 13 mm² and provides a resolution of 260 eV at 10 keV.

A typical x-ray spectrum with Ar injection is shown in figure 2 (a) with the relevant peaks labeled. Figure 2 (b) shows two spectra plotted for different ion confinement times. In both figures the electron beam had an energy of 8.0 kV and a current of 22.4 mA. It can be clearly seen that increasing confinement times leads to increased production of the highest Ar ion charge states. The characteristic K-alpha and K-beta peaks of argon can be clearly seen along with the peaks due to recombination (RR) into the argon L and K shells. K-shell RR is only possible into fully stripped or hydrogen-like ions so existence of this peak is evidence that these high charge states are produced in the trap.

![Figure 2. (a) Typical x-ray spectra of argon and (b) Argon spectra for two different confinement times](image)

3.2. Ion Extraction
It is planned to use the SPARC EBIT as an off-line source providing beams of HCI for the various HITRAP experiments. To measure the charge state distribution of extracted ions two separate techniques have been used; a) magnetic separation and b) time of flight (TOF). For magnetic separation the ion beam is deflected by a H shaped dipole magnet. By varying the magnetic field
ions with a specific mass to charge ratio \((m/q)\) are deflected through 90° and are detected on a Faraday cup. Figure 3 (a) shows a series of magnetic scans taken for a range of trap confinement times with argon gas injected into the trap region. As the confinement time increases from 50 ms up to 1000 ms it is clearly seen that the charge state balance shifts significantly towards higher charge states. However, the total ion current decreases due to increasing period between extractions.

TOF measurements were performed in a reflection geometry. Figure 3 (b) shows a series of TOF spectra taken as a function of trapping potential. All measurements were performed with argon gas injection at an electron beam current of 21 mA and energies of 8 keV. As the trapping potential increases it is observed that the trap capacitance increases leading to increased ion temperatures and hence increased line broadening in the spectra.

![Figure 3](image_url)

**Figure 3.** (a) Magnetic analysis scan of extracted ion beam from the SPARC EBIT with Ar injection. (b) TOF spectra of extracted ions from the SPARC EBIT with Ar injection.

4. **Conclusion and Outlook**

X-ray spectra of trapped ions and charge state analysis of extracted ion beams show that HCI up to Ar\(^{18+}\), Kr\(^{22+}\) and Xe\(^{31+}\) can be produced and extracted from the SPARC EBIT. Simulations suggest efficient injection of ions from an external ion source for charge breeding is possible and experiments in this direction are continuing. A fast multi-parameter data acquisition system has recently been installed and future x-ray measurements will combine this system with a dedicated Si(Li) detector. Using this setup we plan a program of time-resolved x-ray measurements vital for characterization of the charge breeding process. In the near future the current test beamline will be transferred to the HITRAP experimental platform and the EBIT will eventually be used as an off-line source for various precision low energy HCI experiments.

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