DEVELOPMENT OF HIGH CURRENT HEAVY ION SOURCES AT GSI

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Summary

Reflex type sources and an ECR source are being investigated at GSI for the improvement of Unilac performance and new accelerator projects. In first runs with a reflex source, ion currents of up to 4 mA have been achieved for argon, krypton, xenon and mercury from 0.5 cm^2 extraction area. The beam brightness was in the range of 115 to 14 A/(cm mr)^2.

Introduction

At the present time, the ion sources used for Unilac operation are Penning-type. The development of this source has achieved such a level, that most experimental requirements can be satisfied. There are, however, several reasons for starting research activities on ion sources. The lifetime of the Penning-source is sometimes rather short when it is operated in discharge modes required for the production of highly charged heavy ions. In addition, beam current and emittance show a time dependence due to erosion of source and extractor electrodes. For a detailed description of source operation experience see Ref. 1. For isotopes with low natural abundance, ranging from few percent for light ions to about 20% for the heaviest ones, the output intensities of the Unilac are marginal, if natural materials are used in the source. In order to get a better performance in experiments with neutron rich medium mass isotopes, it would be necessary to raise intensities[1] by one or two orders of magnitude to get rid of the dependence on enriched materials. Plans for a synchrotron for relativistic heavy ions, with the Unilac as injector, are based on even higher peak intensity increases, but at a very low duty cycle of only 10^{-4} (100 µs, 1 Hz) compared to 0.25 (5 ms, 50 Hz) of the Unilac. The third aspect for new sources is the inertial confinement fusion with heavy ions. Beams of 50 - 100 mA of singly charged ions of a specific heavy element, are necessary for the rf linac concept to be investigated at GSI.

Source Concepts

For the application at the Unilac two different concepts are being considered. The first is a two stage ECR-type source.[2] In the first stage, a dense, low ionized plasma is produced by microwave heating in a magnetic field. It then drifts to a second stage, where ionization to higher charge states takes place, due to lower background pressure and intensified electron cyclotron resonance heating by microwaves in a magnetic mirror. There should be no lifetime problems, at least for gaseous elements, since this source needs no electrodes. In addition, the current densities in the extraction area will be low compared to a Penning-source, so that negligible erosion and a stable beam can be expected. The distinction between the GSI concept and others proposed for cyclotrons,[3,4] is that this source is for comparatively low charge-to-mass ratios and high current. The design aim is an electrical current of 100 µA of U^{10+} out of the source. The first stage of the ECR source has been constructed. Tests with 2.4 GHz, instead of 14.5 GHz, which is the design frequency, have been performed just recently.

As an alternative to the production of highly charged ions directly within the source, there exists the possibility to produce high current beams of singly or doubly charged ions and strip them to the wanted charge states after an appropriate preacceleration. However, this way is much more expensive than using a source for high charge states, and only justified if very high currents are needed.

In connection with inertial confinement fusion, sources have been developed which deliver 50 to 100 mA of singly charged heavy ions.[5,6] The fraction of doubly charged ions lies between 5 and 10%. This 2+-current would be already enough to increase the intensities from the Unilac as a synchrotron injector, by a factor of 1000. It would require a preaccelerator for 100 keV/u to get the appropriate charge states after stripping in gas. This means that such a source will satisfy both the goals of inertial confinement fusion and of the heavy ion synchrotron. However, the latter application claims a broad range of elements. Several high current source designs were investigated, including even the first stage of the ECR source. The source design which has proceeded furthest, is the so-called picket fence type,[7] which is to be described in the following section.

Ion Source

This approach to getting high currents is based on a source design for neutral injection systems developed at Culham.[8] A schematic of the source is shown in Fig. 1. A cathode disc heated by two filaments delivers the electrons to the plasma. A copper cylinder of 5-cm diameter serves as anode, which is lined with permanent magnets. The two reflector electrodes should reflect the primary ionizing electrons. The extraction is performed by a 7-hole accel-decel system.

The magnets on the anode are arranged to form a 12-pole line-cusp field. Figure 2 shows cross-sections of the source and the radial and axial dependence of the azimuthal field component. A schematic of the electrical supplies is shown in Fig. 3. The source is typically operated with a discharge voltage of 50 to 100 V, and about 40 to 80 A discharge current, at a pulse width of 2-ms and 50-Hz repetition rate. Figure 4 shows the oscillogram of voltage and current for an argon discharge, indicating a very quiet plasma in the source compared to our earlier experiences with high current duoplasmatron sources. The choice of discharge parameters and pulse width was dominated by present limitations of the power supplies; a 300-A power supply is under construction. The disc cathode, developed earlier for GSI duoplasmatron sources,[9] proved to be quite adequate for the high duty cycle.

Experimental Setup

Extraction of ions is performed by a multi-aperture accel-decel system with 7 holes arranged within a circle of 14.4-mm diameter. Its design follows guide lines of the Culham group,[10] developed for single aperture systems. The first experiments used holes with a radius of 2.05 mm. Due to limitations of the extractor supply, the holes presently utilized have only a radius of 1.55 mm, adding up to an extraction area of 0.53 cm^2. With the smaller holes, the optimum extraction voltage lies in the range of 30 kV, with about - 1 kV for the

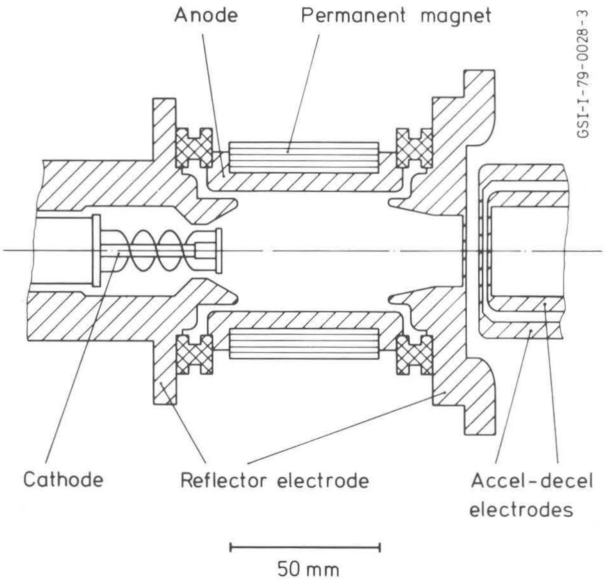

Fig. 1 Schematic of the ion source

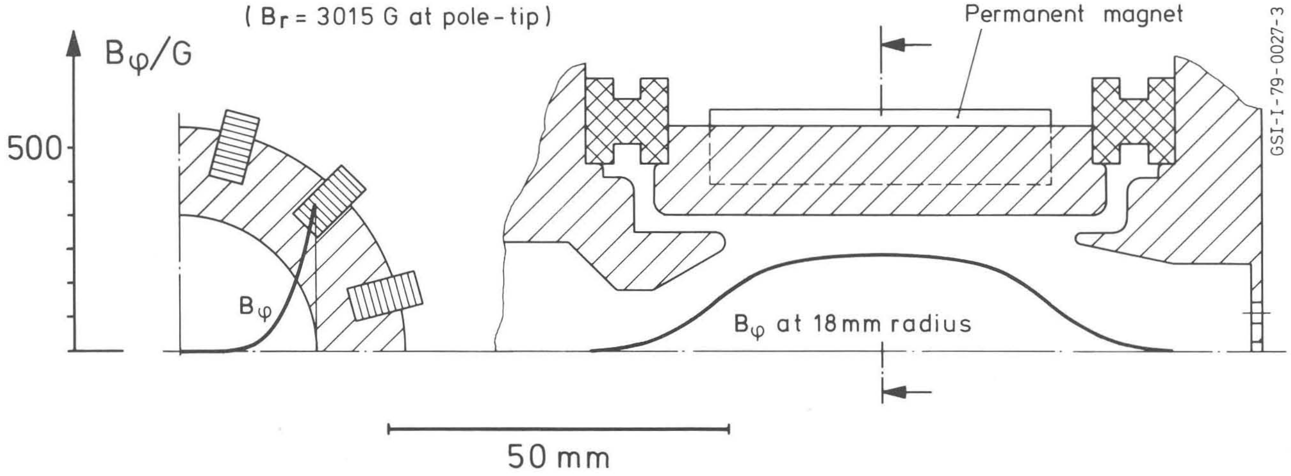

Fig. 2 Azimuthal component of the 12-pole line cusp-field

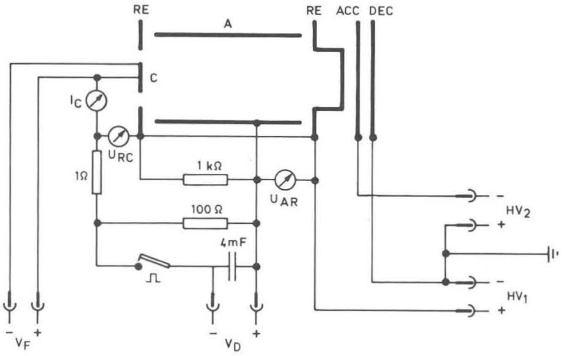

Fig. 3 Schematic of the electrical supplies of the ion source

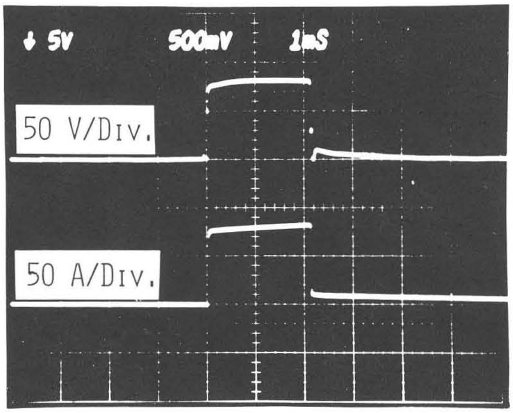

Fig. 4 Source pulse characteristic

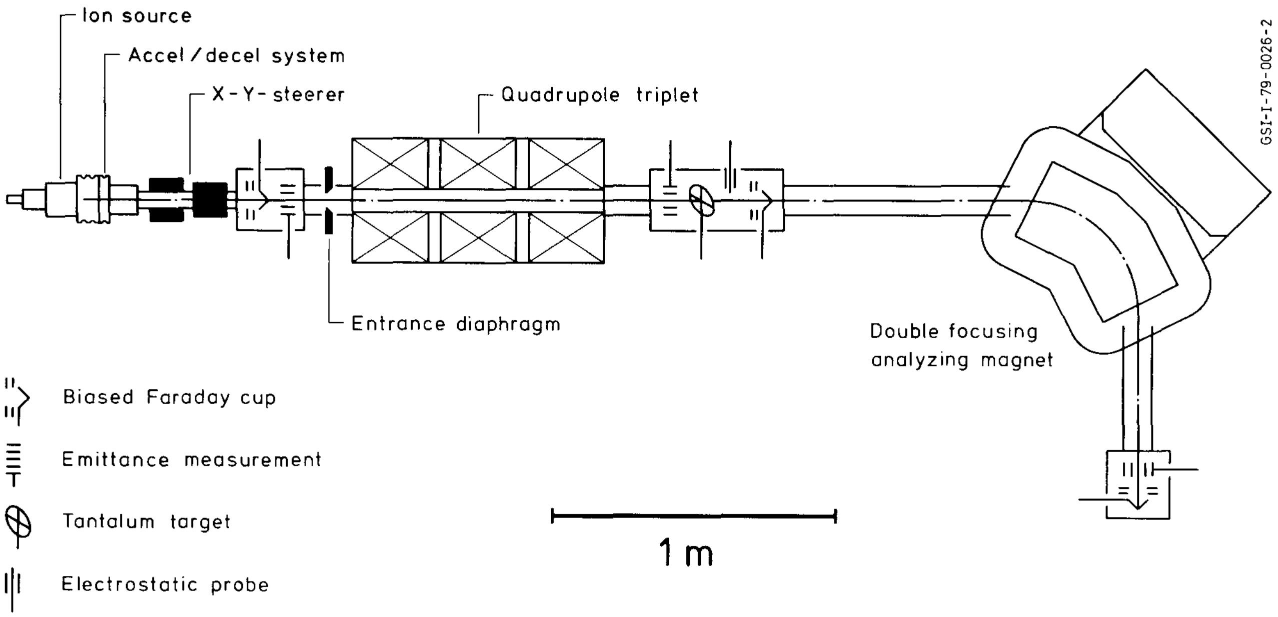

Fig. 5 Experimental Setup

accel electrode, at electrode spacings of 3.8 and 1.5 mm, respectively. Behind the extractor system (Fig. 5), a steering magnet is installed to enable correction of the beam position for the following beam diagnostic systems and for the straight through transport to the analyzing magnet. Biased Faraday cups with additional magnetic electron suppression, are used for current measurements. For the emittance measurement, a pepper pot device is presently used. An on-line emittance measurement device is going to be installed. The quadrupole triplet and the electrostatic probes are under construction. During operation of the source, the pressure in the beam line is about 5 x 10^{-5} Torr.

Experimental Results

The source was operated with argon, krypton, xenon and mercury. For the rare gases, the source runs in the magnet field as shown in Fig. 2. For mercury, a source with a slightly weaker magnetic multipole field was used, substituting for the copper anode cylinder, a slightly different stainless steel cylinder, to avoid build up of amalgam. The beam current was measured with two cups of different design: a short (FC1, 50 mm) and a long (FC2, 200 mm) one. The current-versus-bias characteristics of both cups are shown in Fig. 6. Table I gives the total pulse currents for the different elements, as measured with the short Faraday-cup at a distance of 300 mm from the source. Figure 7 shows a corresponding beam pulse for argon. The pulse is smooth up to 40 mA. One can increase the beam current above this value up to 55 mA, but then it starts showing strong oscillations of up to 20% of the pulse height.

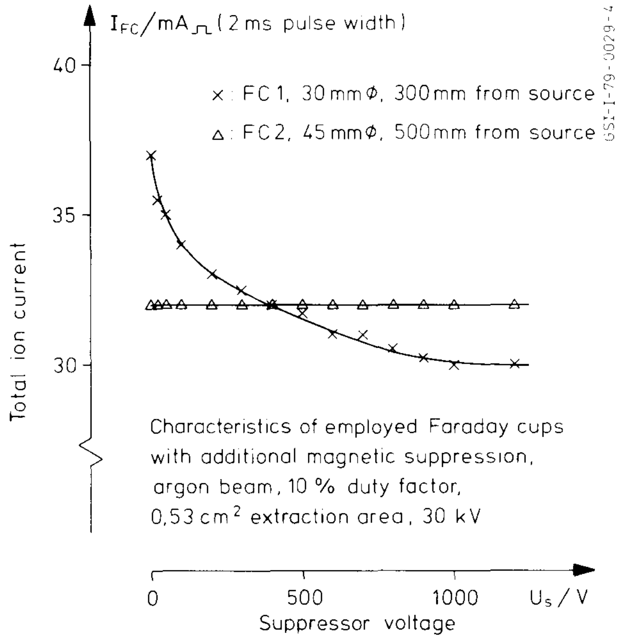

Fig. 6

Due to the high pressure in the beam line and because presently there is no quadrupole triplet available, only a fraction of about 20 % of the total extracted beam has been analyzed in 4.5 m distance from the source. The 2+-portion in Table I corrected for the corresponding emittance, but not for charge-exchange losses. Measurement of the beam emittances was done in a distance of 300 mm behind

Table I

Total beam currents measured 300 mm from the source in a 30-mm diameter Faraday-cup and charge state fractions measured behind the analyzing magnet (≤ 20% of the beam were analyzed). Extraction voltage 30 kV.

Element	Total Current mA (2ms)	Relat. Abundance %	
		1+	2+
Ar	40	97	3
Kr	31	94	6
Xe	26	87	13
Hg	18	93	7

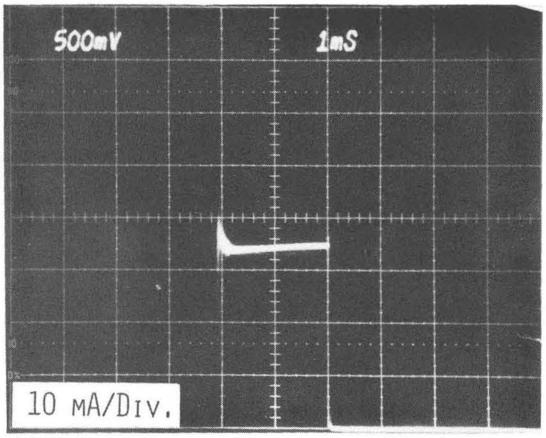

Fig. 7 Argon beam pulse signal measured 300 mm behind the source

the source. The evaluated normalized emittances ε_N, are in the range between 0.015 to 0.017 cm-mrad, thus resulting in brightnesses $B = I/\varepsilon_N^2$, of 115 A/(cm mr)^2 for xenon and 140 for argon.

The experiments with this source are in a very early state. The reflector electrodes could not yet operate biased negative with respect to the cathode, thus ensuring reflection of the primary electrons and reducing the discharge power. With the rare gases, the reflector electrode is biased about +20V with respect to the cathode during the discharge pulse. With mercury, the reflector potential was near to cathode potential, resulting in a reduction of the discharge power: 50%, compared to rare gases for about the same plasma density.

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