IONIZATION EFFICIENCY MEASUREMENTS WITH THE MICROWAVE DISCHARGE ION SOURCE MIDAS

L.Celona, S.Gammino, G. Ciavola, F. Chines, S. Marletta, E. Messina
INFN - Laboratori Nazionali del Sud, Via S. Sofia 44 - 95123 Catania - Italy

Abstract

A microwave discharge ion source (MIDAS) has been designed in order to obtain high efficiencies for positive ionization of the recoils which will be produced with the EXCYT facility at LNS and some experience has been gained from tests with the prototype.

In the mid of 1998 the source has been redesigned: the microwave power at a frequency of 2.45 GHz (2 kW continuous wave) is supplied to the plasma by a microwave line that incorporates a four step binomial matching transformer. The extraction system has also been modified to a three electrode system.

The advantage of such a source with respect to other sources for radioactive beams consists of a ionization process which is not element dependent, thus obtaining quite high efficiencies for light and heavy ions (2% to 50% depending on the base pressure conditions) and of a short delay time (some tens of ms are estimated).

Hereinafter the result of the efficiency tests are reported.

1 THE SOURCE DESIGN

The MIDAS ion source is a compact microwave discharge source which exploits the principle of the off-resonance discharge to generate an overdense-low-temperature plasma which is an effective tool to generate 1^+ ion beams with high efficiency, short delay time and low energy spread.

The prototype of the MIDAS source was tested in 1997-98 [1] but the results were not acceptable with respect to the efficiency request, mainly because of the low RF power coupled to the plasma.

Some modifications have been introduced with respect to the prototype:

- the injection of the microwaves is performed by means of a waveguide with an adequate matching system instead of an antenna;
- the static longitudinal magnetic field is generated by two movable coils instead of one;
- the extraction system is designed to sustain voltages up to 60 kV as demanded by the mass separator design and it is built with three electrodes in place of two;

Figure 1 and 2 show respectively the layout of the microwave line and the drawing of the MIDAS source.

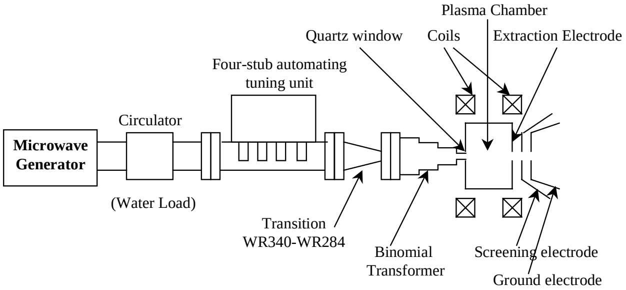

Figure 1: The sketch of microwave line.

The microwave power obtained with a 2.45 GHz - 2 kW magnetron is coupled to the cylindrical OHFC copper plasma chamber (100 mm long and 100 mm in diameter, fig.3) through a circulator, a four stub automatic tuning unit and a binomial matching transformer. The chamber is surrounded by two electrically insulated coils. The variability of a magnetic field configuration is allowed by varying the position of the coils which also are independently supplied. The typical magnetic field profile on the axis of the chamber is flat, slightly above the resonance value (B_{ECR}=0.088T at 2.45 GHz).

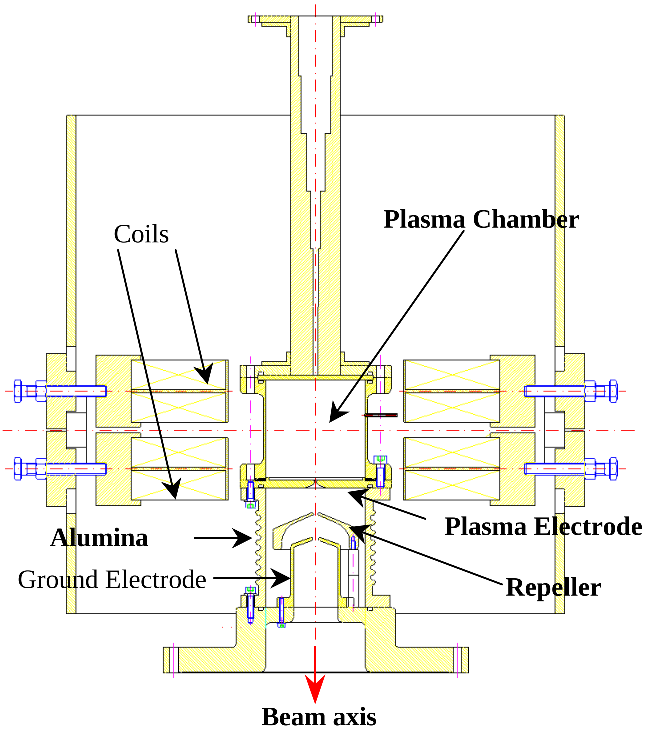

Figure 2: The MIDAS2 source.

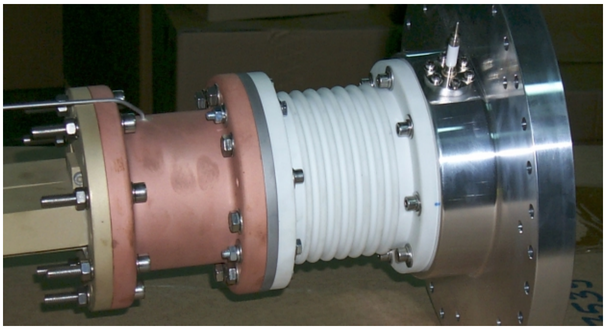

Figure 3: The plasma chamber (left) and the insulator of the extraction system (right).

2 THE MATCHING TRANSFORMER

The most relevant improvement is certainly the multisection quarter-wave transformer used to optimize the coupling between the WR284 waveguide working in the dominant mode (TE_{10} mode) and the equivalent plasma impedance.

A four step binomial matching transformer (fig.4) inserted immediately ahead of the microwave window was chosen [3].

The transformer is designed to concentrate the electric field at the center of the plasma chamber, as it was confirmed by the spot of the plasma on the vacuum window (more intense at the center and decreasing towards the peripheral region with two horizontal lobes). The overall result was a significant increase in the extracted current density.

3 THE RESULTS

The construction of the source MIDAS2 has been completed at the beginning of 1999 and the first tests has been carried out on February.

Most of the test have been performed with a 30 kV insulator, thus limiting the extraction voltage at about 23 kV during operations, because the alumina insulator of the extraction column was damaged.

In spite of these problems, the source has fulfilled our request (the production of singly charged ions is largely dominant and currents up to 30 µA has been extracted for Argon, Krypton, Xenon) with the measured efficiencies ranging between 2% to 50%.

The efficiency measurements were carried out with high precision by means of a system which allows to inject a controlled and variable number of atoms in the source.

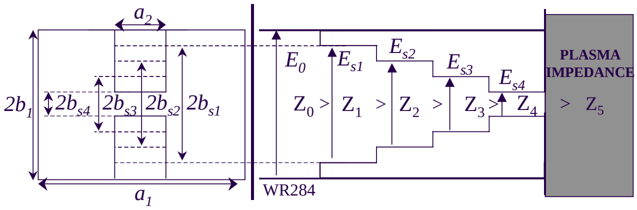

Figure 4: Double ridged four section matching transition.

The gas input pipe of the source has been connected to an equipment based on a precision valve (fig. 5), which leaves a controlled flow to come out from a known volume (V=50 cm^3). The variation of the absolute pressure in this volume gives the number of atoms injected into the source.

The number of molecules N_0 in the volume V at the temperature T is related to the pressure p_0 by the formula:

$$N_o = N_A \cdot \frac{p_o}{R} \cdot \frac{V}{T}$$

where N_A is the Avogadro number and R is the molar gas constant, then the change of pressure Δp in a time Δt can be expressed as a change of the molecules number:

$$\frac{\Delta N}{\Delta t} = N_A \cdot \frac{V}{RT} \cdot \frac{\Delta p}{\Delta t}$$

Finally, the ionization efficiency is given by:

$$\eta = \frac{I_{FC}}{I_{EQ}} = \frac{I_{FC}}{e\frac{\Delta N}{\Delta t}}$$

where: I_{FC} is the beam current measured at the Faraday cup placed at the image point of the analysis magnet and I_{EQ} is the equivalent beam current obtainable if all atoms would be ionized as 1^+, equal to the charge times the number of particles ΔN injected into the source in the time Δt.

Extensive measurements have been carried out for different flow rates. The dependence of the efficiency vs. flow rate is shown in Figure 6 [2].

For Argon a maximum ionization efficiency value around 48% has been measured for a low flow rate not typical for target-ion-source environment and values of 10% 20% have been measured for more realistic flow rate. Results for heaviest ions (Kripton and Xenon) are similar.

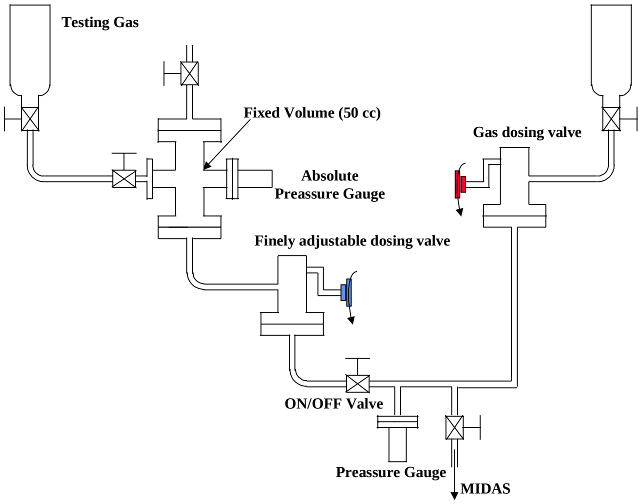

Figure 5: The gas mixing system of MIDAS.

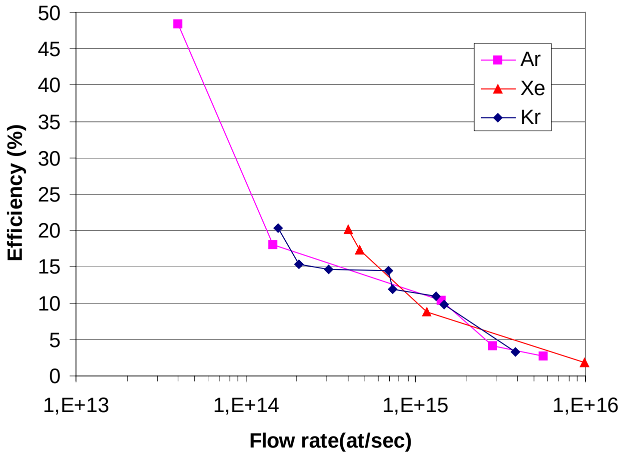

Figure 6: MIDAS ionization efficiency vs. mass flow for different species: all the values has been obtained for the same power level (250 W), the same beam energy (20 keV) and the same magnetic field profile.

Hereinafter some typical spectrum for Ar, Kr and Xe beams are reported. These measurements has been performed at the extraction voltage of 20 kV and with a RF power of 250 W. Higher currents can be obtained with more RF power, but in this case, space charge effects limit the extracted current.

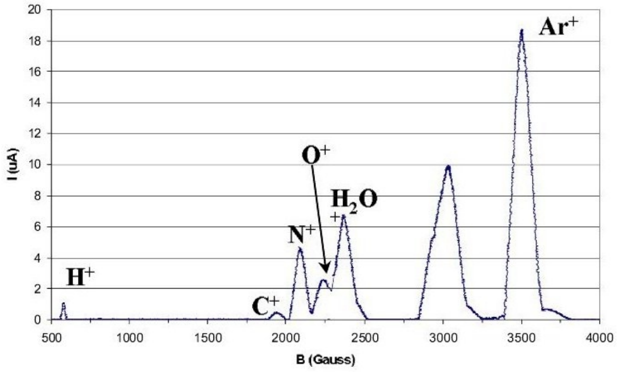

Figure 7: A typical spectrum for Ar beam (flow rate=2.84·10^{15} at/sec).

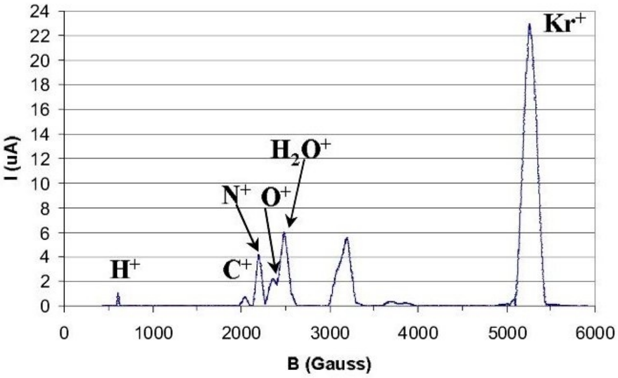

Figure 8: A typical spectrum for Kr beam (flow rate=3.8·10^{15} at/sec).

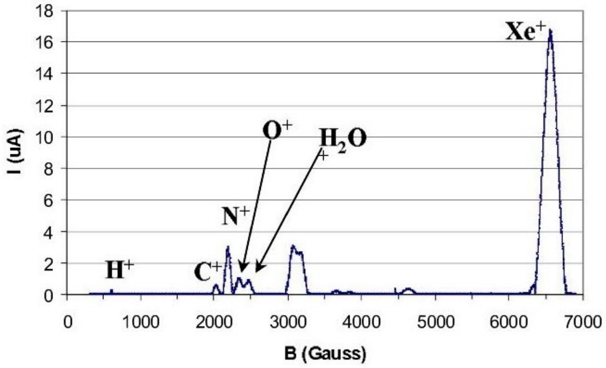

Figure 9: A typical spectrum for Xe beam (flow rate=1.1·10^{15} at/sec).

The dependence of the Xenon beam current from the injected power during a run with a rate of 9.9·10^{15} atoms/sec is shown in fig.10.

Now the source is going to be redesigned, in order to allow the coupling to the target : the above features will be maintained for the most of issues, but the source needs to be adapted to the specific requests of the EXCYT facility [4] (e.g. all the parts inside the high activation area should be dismountable by remote handling).

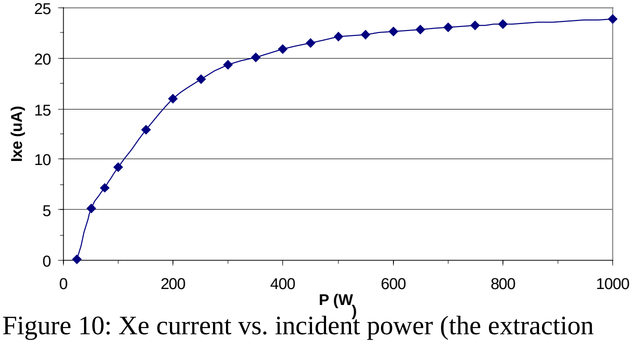

Figure 10: Xe current vs. incident power (the extraction voltage is 20 kV).

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[2] S. Gammino, G. Ciavola, L. Celona, M. Menna, “Ion sources for the EXCYT facility”, Proceedings 5th Radioactive Nuclear Beam Conference, Divonne, April 2000 (print in progress).

[3] L. Celona, G. Ciavola, S. Gammino “ Study on microwave coupling in ECR ion sources and Microwave ion sources ”, Rev. Sci. Instrum. **69**, 1113 (1998).

[4] G. Ciavola et al., these proceedings.