The Grenoble ECR Ion Sources for Accelerators

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Abstract

The last developments of ECR ion sources specifically devoted to the accelerators are presented. Firstly, an upgraded version of the **CAPRICE** ion source is presented. The performances are shown with a special emphasis on metallic element production: both the intensity and the source duty cycle have been improved by using independently heated small ovens. Then, small ion sources whose magnetic configurations are entirely made with permanent magnets are described.

1. INTRODUCTION

Because of their simplicity and their flexibility, the ECR ion sources are well suited to particle accelerators. Depending on wether the source has to be installed on a high platform or at the ground voltage, it is always possible to find an ECR source according to the electrical power allowed. The Grenoble group built the CAPRICE sources for working at ground potential and only permanent magnet built-in sources for high voltage platforms. The first version of the CAPRICE concept has been created by B. Jacquot in 1985 [1]. From that time, this source is constantly improved [2] - [6]. In this article, a review of the main characteristics of the source is done as well as its performances. Then, specially devoted to high voltage platforms, a source entirely built with permanent magnets is presented with a special application.

2. THE CAPRICE ION SOURCE

2.1 Main Features

As already described in previous articles [1] - [4], CAPRICE is constituted of a small plasma chamber (16 cm in length, 6.6 cm in diameter) so that it is possible to operate the source with a rather weak RF power (Figure 1).

The axial magnetic field is created by two sets of coils surrounded by an iron yoke offering a high axial mirror ratio (R = Bmax / Bmin ~ 3.5) and a high magnetic field (1.4 T for a 14.5 GHz operation). A permanent magnets hexapolar structure gives, in the plasma chamber, a radial magnetic field equal to two times the resonance field value: at 10 GHz, a CAPRICE source can run with a 0.8 T hexapole, while at 14.5 GHz, it runs with a 1.2 T hexapole.

The RF coupling system of CAPRICE is another specific feature of the source: the coaxial launching of the RF allows the existence of a very efficient first stage. This first stage is given by the 1^{st} resonance encountered in the coaxial feeder. It usually works with the additionnal gas (support gas) generally used for gases and metals. The efficiency of the first stage is relating to the electron production that feeds the ECR discharge.

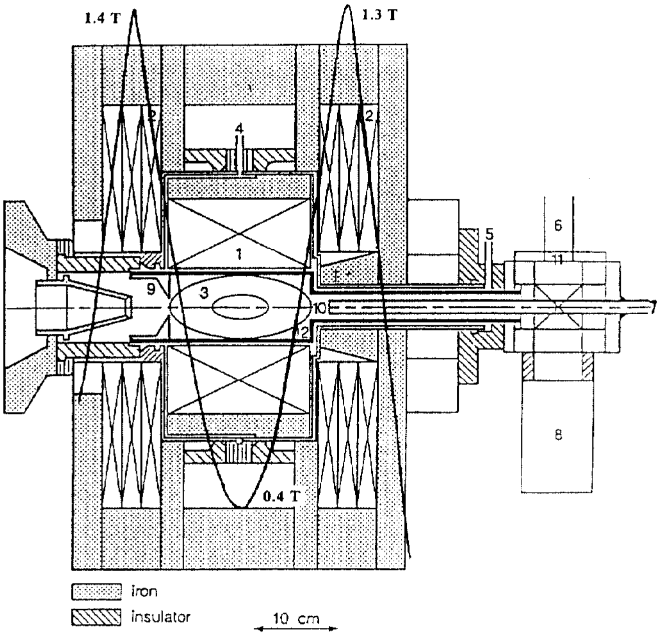

Figure 1. CAPRICE ECR ion source: *(1) magnets, (2) solenoid coils, (3) closed ECR surfaces, (4) water cooling inlet, (5) water cooling outlet, (6) R.F. power inlet, (7) gas inlet, (8) turbo molecular pump, (9) ions extraction, (10) gas inlet tube, (11) R.F. window, (12) removable vacuum chamber.* The profile of the axial magnetic field is also shown for the 14.5 GHz operation.

Another specific feature is the modular design of Caprice that would allow to upgrade any existing Caprice source.

2.2 Performances with Gases

The results presented here have been obtained with our new 14.5 GHz prototype recently built. It is still compatible with the oldest Caprice sources, but has an optimized magnetic configuration for a better trapping of the ions and has also a larger plasma volume. In figure 2 are represented the best performances obtained with two different frequencies. One can notice an improvement of the performances at higher frequency.

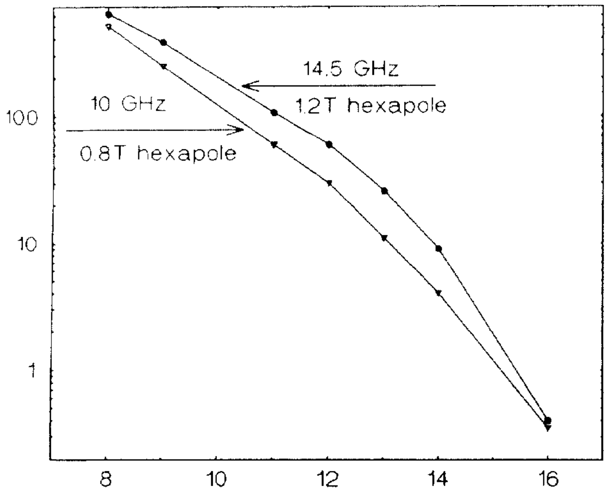

Figure 2. Comparison of the best results obtained at 10 GHz and 14.5 GHz (in eμA) for different charge states of argon.

The well known criterion for the production of multiply charged ions ($n_e\tau_i$) shows that, by increasing the frequency, one can increase the electron density ($n_e \alpha \omega^2_{RF}$). But, it is necessary to have a good electron source and a sufficient confinement time which requires a high mirror ratio of the magnetic well and important axial and radial magnetic fields.

Table 1. Best results obtained with three different sources: AECR [7], SCECR [8] and CAPRICE (in eμA).

	AECR	**SCECR**	**CAPRICE**
Ar^{8+}	-	325	680
Ar^{11+}	161	100	110
Ar^{13+}	53	20	26
Ar^{14+}	24	10	9
Ar^{16+}	2.5	1.5	0.5
Xe^{22+}	48	45	40
Xe^{25+}	68	44	32
Xe^{27+}	37.5	14.2	12

The 14.5 GHz AECR source has a relatively weak mirror ratio (2.5) and a weak magnetic field but has a very efficient electron source [7]. On the opposite, the SCECR source has a huge mirror ratio (7.3) but works at low density (frequency = 6.4 GHz) [8]. While CAPRICE has an intermediate mirror ratio (3.5) and can run at high electron density, but has an insufficient electron source and necessitates further progress in this way. So that one can conclude that this progression in the performances of CAPRICE from 10 GHz to 14.5 GHz is due to a higher electronic density and also to a larger plasma volume. In table 1, are indicated the best results obtained with these three sources.

2.3 Performances with Metals

In this chapter, we present the results obtained with the 10 GHz version.

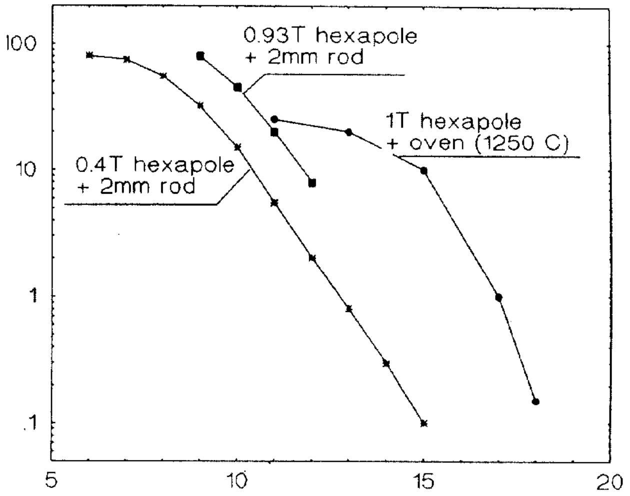

Figure 3. Evolution of the production of iron ions (in eμA) with an improvement of the source itself and with two evaporation methods (plasma heating and oven).

For the production of metallic elements, a wide range of evaporation temperature is encountered. For refractory elements, the evaporation method consits in inserting the desired metal in the plasma so that the plasma itself heats the sample. But with this method, some hot electrons neccessary for the ionization process are lost. Thus, for some metals, a micro oven has been developed [6]. But taking into account the geometry of Caprice, the oven also serves as the coaxial guide of the microwave. With this oven, a few tens of watt are necessary for lead production and with about 100 W, it is possible to evaporate gold and iron. In Figure 3 is shown the evolution of the iron ion production between the Caprice

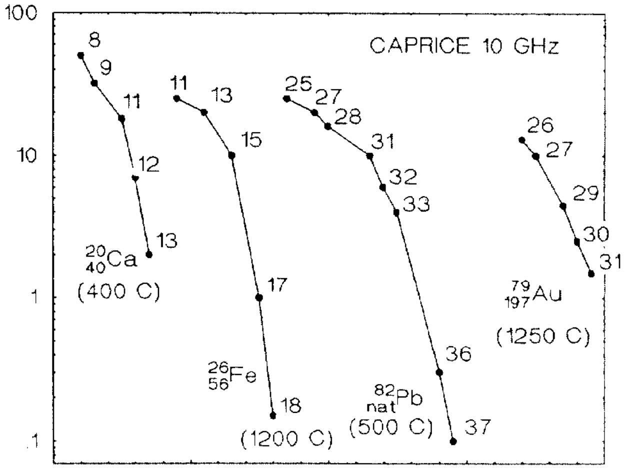

Figure 4. Best results obtained with the use of a micro oven (the intensities are in eμA)

version 1986 and the Caprice version 1993. It is also shown the gain in charge state and intensity with the micro oven as compared with the plasma heating process.

In Figure 4, are represented the best results obtained with the micro oven with the 10 GHz version source. Preliminary experiments done with our new 14.5 GHz source show, as for gases, an improvement in the performances. For example, in the case of iron we have obtained: 100 eμA of Fe^{10+}, 40 eμA of Fe^{13+} and 3 eμA of Fe^{18+}.

3. THE 2.45 GHz PERMANENT MAGNET ION SOURCE

An ECR ion source designed for the use on a high voltage terminal has been recently built. The purpose is to use it for ion implantation with a rectangular beam. The magnetic field is entirely produced by permanent magnets as for the Neomafios source [9]. The body of the source is reduced to a simple cylinder (250 mm in diameter, 250 mm in length) (Figure 5). Three NdFeB permanent magnet cylinders give a magnetic field equal to 0.25 T in the extraction side as well as in the injection region where the RF is introduced, while the minimum B is 0.06 T. Owing to the necessity of having a rectangular beam, the radial field is made of a quadrupole which gives a closed resonance zone at 0.0875 T. The microwave power is injected in the plasma trough an antenna. The extraction slit is 5 mm X 50 mm. With an argon pressure of 2 X 10^{-5} mbar, the extracted current is 3 mA with 100 W of RF power. The first prototype of this ion source can produce stable beams of multiply charged ions at various charge states up to Ar^{8+} as it is shown in Figure 6.

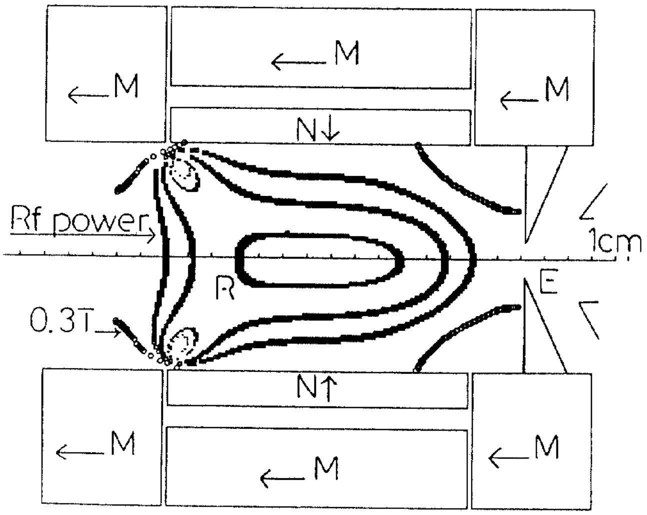

Figure 5. The 2.45 GHz quadrupolar source: axial view and map of the magnetic field inside the plasma chamber (| B | = 875, 1500, 2000 and 3000 Gauss).

But of course, the extraction slit is not an good situation for a efficient multiply charged ion production and the performances of this sources could be easily improved by adding a sextupolar structure instead of the quadrupolar one. A new 2.45 GHz source with such a magnetic structure and a resonant cavity is under construction.

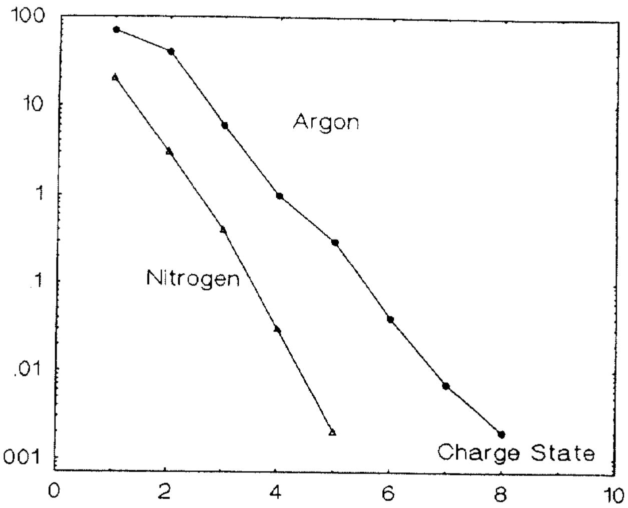

Figure 6. Multiply charged ion production (in eμA) with the 2.45 GHz source equipped with a quadrupole.

4. CONCLUSION

The performances of the Caprice ion source, specially dedicated to atomic and nuclear physics are always improved by a better understanding of each component of the source. The modular aspect of this source makes it easy to be upgraded. On the other hand, a low cost and very simple ECR source is also able to produce multiply charged ions.

5. REFERENCES

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