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STATUS REPORT ON ECR STRIPPED ION SOURCES AT CEN GRENOBLE

R. GELLER - B. JACQUOT

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1. GENERALITES

MICROMAFIOS is a small-scale version of SUPERMAFIOS (Briand et al. 1979, Geller et al. 1980) ; the confinement structure of the magnetic well of the stripper stage results from the superimposition of solenoidal magnetic fields upon a hexapolar magnetic field created by permanent $SmCo_5$ magnets. This innovation leads to a very compact ion source (∿ 50 cm in length) which consumes < 100 kW of electric power (30 times less electricity than SUPERMAFIOS) and less than 2 kW of UHF power to create and heat the plasma. In addition, the coupling of the UHF waves to the plasma, has been simplified to the extreme (fig. 1). The incident wave is not polarised and the coupling is done in multimode cavities, whatever their shape. This eliminates the sophisticated technology of the profiled waveguides used in SUPERMAFIOS and the injection of the UHF power is made into the most convenient part of the mutimode cavity. Thus, one does not take into consideration the theoretical anisotropic propagation of the waves in the magnetised plasma which presents preferential directions depending upon the polarisation modes of the wave and upon the dielectric coefficient of the plasma. One would simply specify that the cut-off frequency of the plasma, $\omega_p = (ne^2/m\varepsilon_o)^{1/2}$ is not reached, i.e. $(\omega_{HF}/\omega_p) > 1$, and also $(\omega_{ce}/\omega_p) > 1$. Then let us simply consider that the ECR stripper stage is :

a) a box whose size is big with respect to the wavelength λ of the incident microwaves ($\lambda \sim 3$ cm, $\omega_{RF} = 10$ GHz) ; therefore the box is homogenously filled with E.M power.

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b) the box is pumped down to a decent vacuum.

c) the box is immersed in a magnetic well structure (B_{min} in the center equals ∿ 2.5 KG and B_{max} ∿ 5 KG around). Subsequently in between exists a closed 3.6 KG magnetic surface of quasi elliptical shape where ECR occurs. (For 10 GHz this surface is characterized by a isomagnetic field strength of ∿ 3600 gauss).

d) electrons crossing this surface are necessarily accelerated by an ECR effect, because on this surface there is necessarily an electric field $\tilde{E}$ component due to the multimode wave pattern, which is perpendicular to the 3600 gauss field lines and exerts a force $F = e(\tilde{E} + v \wedge B)$.

e) according to the phase conditions the electron is either accelerated or decelerated by passing through the ECR surface.

f) if the electron passes many times through the ECR surface then it is globally heated. (Stochastic heating).

g) if the heating is not degraded by inelastic collisions (for instance fully ionized Hydrogen plasma) then a theoretical study [ ] shows that the electron temperature T_e reaches a limit given by :

$$T_e^{keV} \sim \left[P_{RF}^{Watt}\right]^{k} \text{ where } k \simeq 0.5.$$

h) if losses, due to inelastic collisions (multiple ionizations, excitations, recombinations, radiations etc...) occur then the exponent k is smaller than 0.5. For instance $k \lesssim 0.2$ for a Xenon plasma with average charge state $\langle z \rangle \sim 6$.

2. THE MICROMAFIOS SOURCE : DESCRIPTION AND RESULTS

The UHF frequency used (- 10 GHz) is the same in the first and in the second stage . Fig. 1 also shows the axial and radial magnetic field . We note that the magnetic field in the first stage created by the solenoidal coils S1 is increased by the presence of the soft iron screen F1. The resonance zone is located in a region of high gas pressure (10^{-3} Torr) in the gas injection pipe made of a dielectric material, which is found well inside the multimode cavity C1 ; the pumping speed of the turbomolecular pump P1 is 100 $dm^3\ s^{-1}$. UHF is injected into the cavity by means of a circular waveguide and a window of beryllium oxide. A diaphragm D separates the cavity C1 from the drift space G ; the latter region is pumped by P2 (at 100 $dm^3\ s^{-1}$), the gas pressure being $< 10^{-5}$ Torr. An appropriate conductance separates G from the stripping stage C2 where the gas pressure is decreased by a factor of 10.C2 is made up of a parallelepiped box and a cylinder whose dimensions are : diameter, 7 cm ; length, 30 cm. The whole body made of stainless steel constitutes the multimode cavity and it is pumped through the two extremities. A cryogenic pump P3 whose pumping speed is 1000 $dm^3\ s^{-1}$ is placed upstream under the parallelepiped box whilst a turbomolecular pump P4 is found downstream. In the steady state, the residual gas pressure in C2 is $\sim 10^{-7}$ Torr whilst in working conditions the pressure is $\sim 10^{-6}$ Torr. The permanent magnet hexapole surrounds the cylindrical part of the C2 cavity and at one of its extremities, the ionic extraction is made beyond the magnetic mirror. Radiation (UHF 2) is injected into the parallelepiped box of the cavity C2 through a leak-proof window F2. The whole structure of the ion source is isolated and the applied potential is < + 8 kV. It is important to make sure that the closed magnetic surface where ECR occurs does not intercept any wall. The part played by this surface is double. It heats the electrons and represents roughly their magnetic reflection surface. Therefore it also constitutes a surface of ionisation for neutral atoms, i.e. an ion pump "in situ". Finally the density of neutral atoms inside the resonant surface (where the plasma is confined) is probably more than one order of magnitude smaller than outside where the pressure is measured (10^{-6} Torr). Under these conditions charge exchange recombination of the ions can be limited in the stripper stage without ultra-high vacuum pumping and large vacuum conductances.

The adjustable parameters are : gas flux (< 2 $cm^3\ h^{-1}$), power UHF 1 and UHF 2, pulsed (at variable lengths) or CW regime, and the extraction voltage. The charge state distribution of the multiply charged ions was made by a high-power high-resolution magnetic selector followed by a Faraday cup. In this paper we present a serie of measurements at a low extraction voltage (< 8 kV) ; the diameter of the extraction hole is 8 mm. The ion currents (in μA) for the different species collected in the Faraday cup are summarised in table 2.

The emittances of the beams have been measured. For beams in the range of 0.1 to 1 μA, they are generally between 50 and 300 mm mrad. For higher currents they exceed this value. Figure 3 shows a spectrum of nitrogen isotope ions and figure 3 shows the shape of some oxygen ion currents against time. We see that the equilibrium for highly charged ions is reached only after milliseconds whereas lowly charged ions are rapidly obtained. The depletion of their intensity in the first stages of the pulse, indicates that step-by-step ionisation transforms the low-charge ions into more highly charged species. The ionic currents of the table are given for the plateau values. The results for oxygen and nitrogen are obtained with a gas mixture of 80 % of the isotopes ^{18}O, and ^{15}N. This allows separation of the completely stripped ions from the H_2^+ ion (H_2^+ is the result of wall-degassing of the source and also of dissociation of H_2O molecules). The obtention of quasi-continuous, clearly separated beams of completely stripped ions emerging directly from an ion source is an original and unique achievement. The production of completely stripped ion beams with Z/M ratios of 1/2 (like $^{12}C^{6+}$, $^{14}N^{7+}$, $^{16}O^{8+}$ and $^{20}Ne^{10+}$) is particularly interesting for fixed-frequency cyclotrons normally working with hydrogen ions. MICROMAFIOS worked on a test stand for cross-section measurement. Only one breakdown happened during 12 months of daily operation. The origin of the breakdown which is still unclear, obliged us to dismount the source (2 days of repair) and replace one ferrite which was locally demagnetized. Evidently the demagnetized spot (area ∿ 2 mm²) was consecutive to a local heat excess ; when and under what conditions this accident arrived could not be determined. (One can imagine : a cooling default of the hexapole, a local spark on the vacuum chamber, a sudden decrease of B with maximum microwave power present etc...).

3. THE MINIMAFIOS SOURCE : DESCRIPTION AND RESULTS

In order to simplify even more the ECR source, and to minimize its tuning (and eventually obtain a push-button source) we tried to compound the first and second stage of MICROMAFIOS in a unique microwave cavity. There, the microwave power creates the cold plasma in a first ECR zone and heats the electrons on a second ECR surface where the plasma is confined in the same conditions as in MICROMAFIOS (i.e. the same Bmin structure). Finally one can see on fig. 5 that the second stage remained unchanged but that the first stage is reduced to a dielectric tube G where ECR_1 creates the injection plasma. The conductance of the G tube, is such that the gas pressure drops there from 10^{-3} to 10^{-5} Torr when gas is introduced with the needle valve.

The operation mode of MINIMAFIOS is different of MICROMAFIOS because ignition of the source must be triggered at a higher gas pressure. Similarly to arc sources, one ignites the plasma at 10^{-4} Torr (with low RF power) and then gradually one decreases the pressure and increases the RF power to optimize the highly stripped ion production. After 15 minutes this optimum is generally reached and the performances of MINIMAFIOS are then very similar to those of MICROMAFIOS. The reliability of MINIMAFIOS seems good but the reproduction of the best performances can takes some time and tunings. On the other hand if during the pressure tuning the plasma extinguishes, hard X-rays can be produced by run away electrons, and microwave power is reflected (no plasma electrons are then available to absorb the power).

However MINIMAFIOS gives good results if one does not look for the highest charge states. (It can always replace favorably an externe PIG source). O^{5+}, O^{6+}, Ne^{7+}, Ne^{8+}, Ar^{9+} and Ar^{10+} ions are obtained in routine regime with similar currents and emittances than those given by MICROMAFIOS and finally MINIMAFIOS is smaller, 20 % cheaper and dissipates 15 KW less electrical power.

4. ECR SOURCE RESEARCH AND DEVELOPMENT

a) A 25 KV high voltage plateform for MICROMAFIOS :

Accelerator people need variable energy for stripped ion injection and according to the requirements for the Groningen and Grenoble cyclotrons, source potentials up to 25 KV are desirable. Until now only 7 KV insulation was provided for MICROMAFIOS. New insulators for the body of the source, the coils, the cooling system and the waveguides have been studied and manufactured. The source is now ready but a general electric power breakdown delays presently the beginning of the tests. In parallel to the higher extraction potentials a more sophisticated beam optics will be tested, and enabling a possible increase in the extracted ion current.

b) MICROMAFIOS series and preseries :

The contact for a small series of MICROMAFIOS is now ready for signature with CGR MeV Company. A minimum yield of 1 source per year is foreseen ; the first source should be ready in 1983. On the other hand the preseries will be ready at the beginning of 1982 and their delivery to K.V.I. Groningen and I.S.N. Grenoble are planned before spring 1982.

c) MICROMAFIOS upgraded :

Such a source will be studied by our group. The hexapole of $\leq$ 8 KG in Samarium Cobalt compatible with a 16 GHz microwave power, 10 KW, is presently under consideration. No time schedule is fixed but a 3 year time span for its construction looks reasonable. As far as metallic ions are concerned a research and development program has been proposed but the financial support is not yet assured.

SOME REFERENCES

BRIAND P., CHAN TUNG N., GELLER R., JACQUOT B., GISI Report P-3-77, Darmstadt (june 15) Ed. Wolf & Klein (1977).

BRIAND P., GELLER R., JACQUOT B., JACQUOT C., C.R. Acad. Sci. B 28 559 (1975).

GELLER R., 13th Int. Conf. Phenomena of Ionised Gases, Berlin (1977) p. 103 - IEEE Trans. Nucl. Sci. NS-26 2120 (1979).

GELLER R., JACQUOT B., PAUTHENET R., Revue Phys. Appl. (mai 1980).

DOUSSON S., GELLER R., JACQUOT B., Low En. Ion Beams, 2nd Intern. Conf. Bath (GB), 14 april 1980, Ed. The Institute of Physics by Wilson and Stephens.