Operation of the Legnaro ECR ion source

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Abstract

First results of extracted beams from the ECR ion source Alice for oxygen and argon are presented, after discussing source assembly. Under the present limitations to the total microwave power (100 W) and to the extraction voltage (9 kV), from a helium-oxygen plasma a 230 μA beam is extracted, and the charge state distribution (CSD) indicates an effective electron temperature of 249 eV. Adjustments of the gas flow conductances and of the removable first stage are indicated.

1 SOURCE DESCRIPTION

The Electron Cyclotron Resonance [1] (ECR) ion source named Alice [2], was installed and tested in the Machine Division Test Hall of LNL ("Laboratori Nazionali di Legnaro") in December 1991. Alice is a very compact 14.4 Ghz ECR ion source with a relatively low power dissipation (31 kW) in the coils (Fig. 1), well adaptable to be mounted on a high voltage platform [3], [4] , [5].

The magnetic field configuration features a Halbach NdFeB hexapole and two independently powered coils making a two mirror main field, or 2nd stage field. The minimum field at the walls may reach $|B| = 7.4$ kG, at the 95% current of the two power supplies, both rated 640 A/ 29 V. A new feature is a removable plasma chamber (RPC), separately cooled, and housing all the obstructions, the pumping holes, the waveguides and the RF meshes which determine the gas flow and the microwave coupling to the source. This chamber also houses a 30 mm outer diam iron ring, which produces the first stage two mirror field. The forward microwave power P_k produced by the klystron is divided and is partly reduced with E-H tuners, so that the first stage waveguide receives a power $P_1 = 0.075 P_k$ and the second stage one receives $P_2 = 0.6 P_k$. A strong reflection (about $0.2 P_k$) was observed from the second stage.

1.1 Beam line and current measurements

As usual, the plasma and the surrounding walls are held at a positive potential V_S with respect to the following beampipe. Since some plastic covers are not yet installed around the source head, we are limited to $V_S = 9$ kV. The extracted[6] beam is matched by an einzel lens to an analysis dipole, which bends the selected ion species by 90 degrees and focus it on a designed buncher position, located 1.15 m downstream. By rising the einzel lens voltage, it is possible to focus the selected beam on the measuring Faraday cup, at a distance $L = 0.65$ m downstream the dipole; the optimum einzel voltage was $V_e = 3.(8)$ kV$= 0.42 V_S$.

The Faraday cup was designed for maximum rejection: the beam must pass a $d = 12$ mm hole in the 96 mm diam collimator, placed before the cup; the mass resolution $\Delta M/M$ is better than $2d/L = 1/27$. Since the two designed X-Y steerers are not ready, it is well possible that the desired ion species hits only partially the Faraday cup; indeed the collimator current I_c is from three to ten times the Faraday cup detected current I ; note that I_c may be affected by scattered beam, by nearby deflected ion species and by electron emission. As usual, we have also a suppressor electrode (biased to $V_d = -251$ V) to reduce the electron emission from the cup; a 10 % increase in I was observed turning it off.

The extracted total beam current I_b was measured by difference of the HV power supply current I_S with klystron on and off.

1.2 Cooling the plasma chamber

A major difficulty is to provide cooling water to the removable plasma chamber. To avoid the use of electroformed nickel bellows (both expensive and magnetic), we tried a rather rigid 0.4 mm thick stainless steel tube. Each of the two tubes (in,out) is coiled (Fig. 2a), providing the necessary flexibility so that the free end can be pulled out from the vacuum chamber for connecting and disconnecting the water feedthrough (a 8 mm diam custom copper gasket seal is used). The assembled system showed major leaks when vacuum tightness was tested; a possible explanation is that the stresses, developed when we push the feedthrough in place, loosen the copper seal. It seems that a short bellow section in the water feedthrough can prevent this problem.

A way to circumvent this difficulty is to weld the tubes directly to a CF100-like two side flange on the source head (Fig. 2b), just making the removable plasma chamber a little longer (from 46 to 60 cm). We plan to implement this in the April shutdown of the source.

To reduce risks of heating the hexapole and/or of melting the removable plasma chamber, now not cooled, we limited $P_k < 100$ W in continuous wave.

2 EXPERIMENT WITH GASES

2.1 Gas flow and pumping

The dosing gas valves, located near the source, are manually operated through a mechanical transmission from outside the 0.5 m thick wall, shielding any possible Alice X-

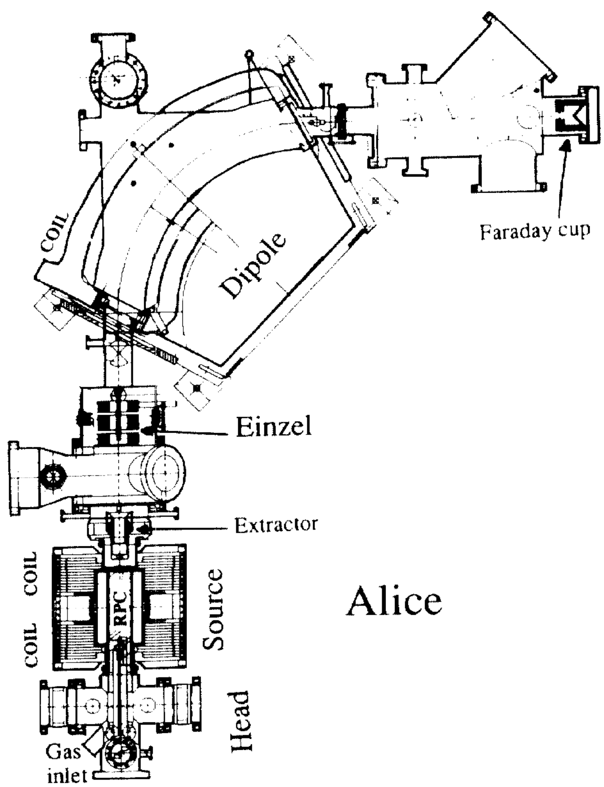

Figure 1: Section of Alice and its beamline.

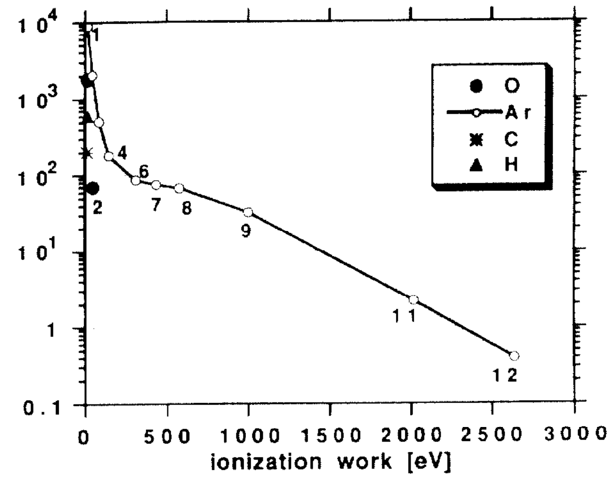

Figure 3: An argon plasma yield: we plot also some clearly identified impurities. The numbers indicate charge state.

rays. The source Alice has three gas lines, one leading directly to the 2nd stage chamber (presently unused), the other two merging into the "gas mixing tank" (a 2 cm diam 4.5 cm long cylinder), from which a 4 mm diam 20 cm tube channels the gas to the first stage chamber, rather efficiently connected by a manifold (15ℓ/s conductance) to a first turbopump (TP1). The first stage chamber is connected only by a 5 mm diam snout to the second stage, which is pumped by a second turbopump (TP2) via another manifold (20ℓ/s conductance) and by the extractor turbopump (TP3) via peripheral holes in the extractor electrode copper cover (50ℓ/s conductance). Three Penning gauges are installed, but we can read only the extractor region gauge (pressure P_3), the optical fiber link reading P_1 and P_2 being not yet connected.

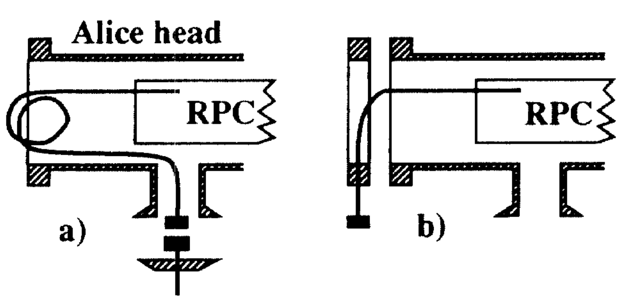

Figure 2: Detail of cooling water connection to the the removable plasma chamber: a) coiled tube with joint b) welded tube.

By observing the light emitted by source (reflected by one mirror to protect ourselves from X-rays), it was found no clear evidence that the first stage plasma is on. This is far from being conclusive, but indicates that the first stage pressure may be too low and that trying the usual alumina tube confined first stage is appropriate.

2.2 *Pure gases*

The first gas used was argon; since the Ar^{+11} current was not increasing with the solenoid current I_1 , I_2 as expected, equipment was checked, finding that I_1 was unstable over $I_1 > 330$ A. Fixed it, the expected increase was obtained, allowing for a easy reproducibility of Ar^{+12}; Fig. 3 show results for $I_1 = 544$ A and $I_2 = 529$ A, $P_3 = 2\ 10^{-7}$ mbar and total power $P_k = 80$ W; the total beam current was about $I_b = 1\ 10^{-4}$ A.

From empirical considerations [7], it is expected that the current $I(q)$ of the ions X^{q+} , where X is a main element of the plasma, follows a maxwellian distribution:

$$I(q) \propto q \exp(-W(q)/kT) \tag{1}$$

where $W(q)$ is the work required to ionize X to X^{+q} and T an effective electron temperature. From the slope of the line from Ar^{+9} to Ar^{+12} of Fig. 3, we get $kT = 3(77)$ eV.

Turning to a pure oxygen plasma, it was difficult to stabilize the pressure to less than $P_3 = 3.6 - 3.9\ 10^{-7}$ mbar; setting $I_1 = 507$ A, $I_2 = 481$ A and $P_k = 80$ W, we get a total beam current $I_b = 300\ \mu$A and the results shown in Fig. 4. As in the argon case, we find $kT = 16(5)$ eV.

2.3 *Mixing gases*

The stability of the gas flows is more important when two gases are mixed, since their mixing ratio is not measured

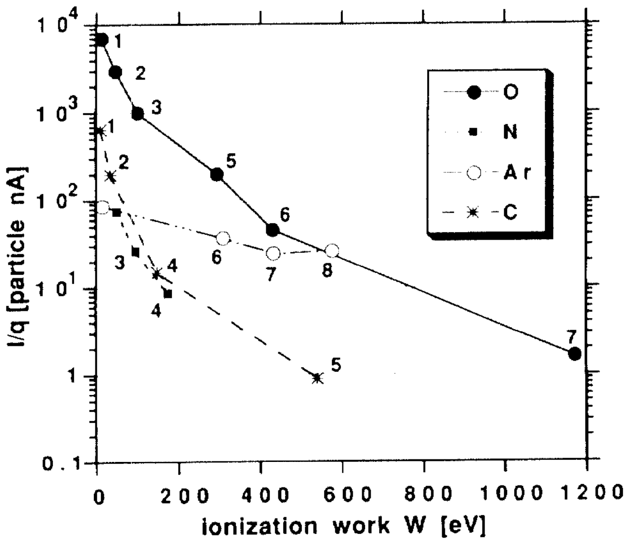

Figure 4: An oxygen plasma yield: note argon impurity.

directly. The accuracy of manually adjusting the pressure knob was much finer than the stability of the pressure P_3 itself at fixed knob, because of several processes: i) outgassing from beam impact, fluctuating as the current I , read by the Faraday cup; ii) decrease of the gas supply pressure; iii) memory effect of the walls: opening the oxygen dosing valve after a long closure, caused a better O^{7+} output at a first time. Later on (one hour) the O^{7+} output significantly decreased and the total pressure P_3 increased; regulating or closing the oxygen then produced no appreciable recovery of the previous values of P_3 and of the O^{7+} output (in a 10 minutes time).

While i) and ii) can be easily avoided, the memory effect limited the results of our effort in using oxygen as a buffer gas so far; some better measuring and understanding of the process itself will be required. We speculate that a possible contribution comes from the inner surface of the cooling circuit, now exposed to vacuum (see section 1.2); this will be obviously tested when cooling circuit is fixed.

Adding oxygen to argon has not yet produced any improvement, as it is consistent with the limited stability of oxygen input to the plasma. On the contrary by adding a small quantity of oxygen to an helium plasma, we get our best results for oxygen (see Table 1) with $I_1 = 554$ A, $I_2 = 529$ A, $P_k = 70$ W, $P_3 = 2.3-2.7\ 10^{-7}$ mbar. The total extracted current was $2(30)\mu$A and we get $kT = 249 \pm 7$ eV from figure 5.

Ion and charge	I typical[nA]	I best [nA]
He^+ and O^4	40000	
He^{++} and H_2^+	8750	
H^+	4750	
O^+	7500	
O^{++}	4000	
O^{3+}	3000	
O^{5+}	3500	
O^{6+}	4000	
O^{7+}	235	300

Table 1: Detected current of principal ion species for a mixture of helium and oxygen.

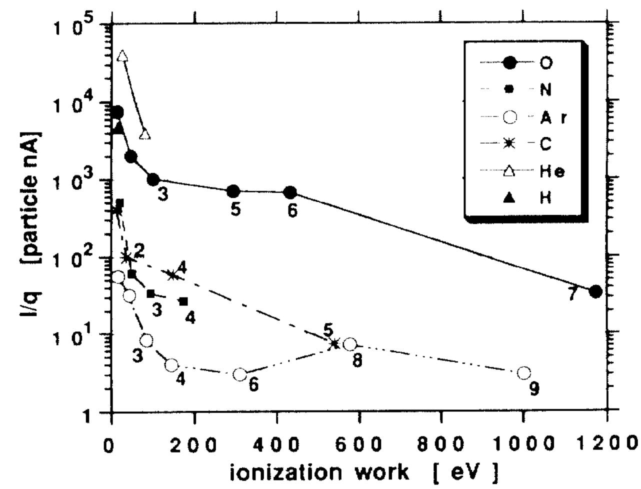

Figure 5: A helium-oxygen plasma yield.

Since the extracted current I_b was below the Child-Langmuir [6] limit value $3.5\ 10^{-4}$ A for the three case before reported and actually for any operating condition with $P_3 < 5\ 10^{-7}$ mbar, we conclude that the gas is too readily pumped out of the second stage, limiting the plasma density; therefore an extractor with less pumping holes must be also tested.

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