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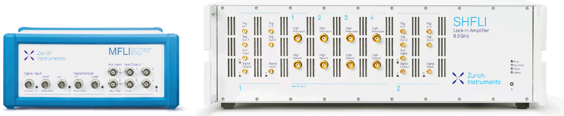

Effect of the Plasma Chamber Radius on the High Charge State Production in an ECR Ion Source

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Abstract. Two versions of the 18 GHz PHOENIX ECR ion source have been developed in the framework of the SPIRAL2 project. The former design (V2) has a compact plasma chamber volume of 0.6 liter with a diameter of 62 mm. A new design (V3) has been developed at LPSC with a larger diameter of 89 mm (chamber volume 1.4 liter) with enhanced pumping features. Since the two versions have nearly the same axial mirror structure and the same radial magnetic field intensity at the wall, it is of interest to compare their performances as a function of the plasma chamber radius. Experiments have shown an improvement of high charge state production of Argon between V2 (45 µA Ar^{14+}, 6 µA Ar^{16+}) and V3 (120 µA Ar^{14+}, 58 µA Ar^{16+}). Results are discussed and explained as a consequence of the increase of the ECR zone volume.

HIGH CHARGE STATE PRODUCTION IN ECR ION SOURCE

Electron cyclotron resonance ion source (ECRIS) are used to produce multi-charged ion beams for particle accelerators. A wide variety of ion sources are used with various operating resonant frequency and plasma volume. It is empirically observed that large plasma chamber volume ECRIS produce higher intensity of high charge state (HCS) ions than compact ones [1,2,3]. Many parameters affect the HCS production in an ECR plasma: the residual gas pressure, the magnetic field intensity and topology confining the plasma, the microwave power injected, the plasma chamber length and diameter. These macroscopic parameters affect the plasma parameters determining the charge state production in the plasma: electron energy distribution function (EEDF), ion confinement time, plasma density, ion creation and destruction rates, etc. It is commonly accepted that the dense plasma is located inside the closed ECR magnetic surface whose boundary is defined by $B_{ECR} = 2\pi f m_e/e$, f being the microwave heating frequency. Along with the source magnetic confinement, it is also commonly admitted that HCS ions are confined electrostatically in the ECR zone by the presence of a potential dip[4,5] located at the ECR surface. The total rate of ion creation and destruction is proportional to the plasma density, the EEDF and obviously by the plasma volume, identified in this work as the ECR volume.

EXPERIMENTAL MEASUREMENT OF A VOLUME EFFECT AND DISCUSSION

Evaluating a volume effect on HCS production between different ion sources is difficult since other parameters than the volume vary from one ECRIS model to another. The two versions of the 18 GHz PHOENIX ion sources, named V2 and V3, developed for the SPIRAL2 accelerator, have the interesting feature of being very similar, apart from their plasma chamber radius[6,7]. The main ion sources parameters are summarized in table 1. One can see that V2 and V3 have practically the same axial and radial magnetic field intensity at wall. One can note the much larger

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ECR zone in V3 (95cm^3) with respect to V2 (25 cm^3, see also figure 1) and an ECR surface, able to absorb microwave, twice higher for V3 (147 cm²) than for V2 (75.8 cm²). The V3 design includes a vacuum chamber located at the source injection equipped with a pressure gauge and a turbo-molecular pump, leading to a reduction of the source residual gas pressure with respect to V2. Another pressure gauge, common to V2 and V3 tests, is located on the extraction vacuum chamber. Because the beam tests on V2 and V3 were performed on the same beam line and because the extraction pressure is correlated with the injection pressure during operation, it was possible to estimate the pressure in the V2 plasma chamber helped with the pressure measured at the extraction. Ar^{14+} beam optimization was performed on both ion source version and compared. Figure 2 (a) shows the best argon charge state distribution (CSD) obtained with PHOENIX V2 (blue bars). The gas pressure in the plasma chamber was estimated to 4×10^{-7} mbar and the microwave power at the emitter was 1 kW. Further optimization of the source: argon pressure reduction, RF power increase, was unproductive or lead to degraded performances. Result of optimization of Ar^{14+} beam with V3 is displayed in red for the same pressure. The RF power injected from the emitter was 1.8 kW, limited by the klystron output power. One can see an overall enhancement of the argon beam intensities. This effect is understood as a volume effect: indeed with a larger ECR zone, the ion creation rate is higher provided the plasma density and EEDF are kept constant. The RF power density in the plasma is 40 W/cm^3 for V2 and 19 W/cm^3 for V3, while the RF power surface density to the ECR zone is practically the same for V2 and V3 (13 and 12 W/cm² respectively).

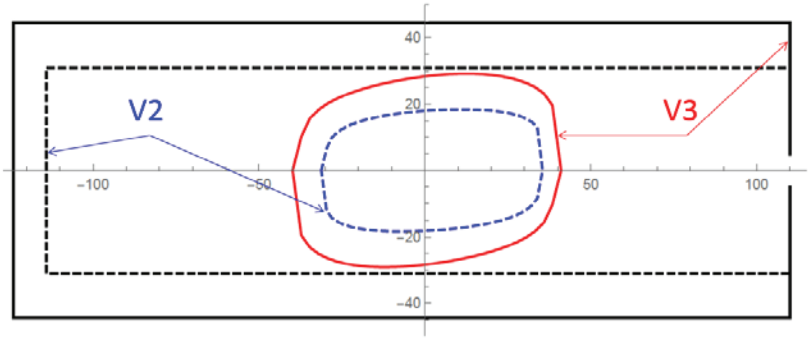

FIGURE 1. Sketch showing the plasma chamber dimension and ECR zone for PHOENIX V2 (dashed lines) and PHOENIX V3 (solid lines). ECR zone for V2/V3 are respectively blue/red.

TABLE 1. Main parameters of PHOENIX V2 and V3 ion source

Ion source	V2	V3	Unit
Plasma chamber diameter	62	89	mm
Plasma chamber length	195	210	mm
Plasma chamber volume	0.67	1.45	liter
ECR zone surface	75.8	147	cm²
ECR max. length	65	80	Mm
ECR zone volume	25	95	cm^3
ECR max. diameter	36	56	mm
Injection peak field	2	1.95	T
Min. field	0.49	0.49	T
Extraction peak field	1.2	1.2	T
Mean Radial field at wall	1.18	~1.2	T

Next, the argon pressure was reduced to find the best optimum for Ar^{14+} in V3. The CSD obtained with a pressure of 2.2×10^{-7} mbar is displayed in red in figure 2 (b) and compared with the former V2 best reference spectrum. The Ar^{14+} intensity reaches now 120 µA instead of 45 µA. Further reduction of the pressure (P= 1.9×10^{-7} mbar) made the CSD shift to higher charge state, giving 58 µA of Ar^{16+} (the record for V2 was 6 µA). In V2, reducing the pressure further or increasing the RF power leads to instabilities, likely produced by overheated electrons or coming from chaotic particle flux extracted from the chamber wall and contaminating the plasma. This major improvement is analyzed as both a consequence of the increase of the ECR volume and a reduction of the plasma chamber residual gas pressure. Arguments are as follows (see explanation afterward). Firstly, the enlarged plasma chamber radius results in a reduction of contaminant density in the plasma which are known to significantly degrade the mean plasma CSD in an ECR plasma. Indeed, the flux of atoms desorbed or sputtered from the wall is proportional to the plasma chamber surface, while the ionization processes occurring in the plasma are proportional to the chamber volume. For a cylinder with radius r and length L, the surface to volume ratio is $\frac{S}{V} = \frac{2}{r} + \frac{2}{L}$. Hence, an increase of the cylinder dimension r or L reduces $\frac{S}{V}$, resulting in a reduction of density of contaminants in the plasma (~-27%) and finally improving the HCS production. A second argument favoring the HCS production is the higher confinement time induced by the larger plasma chamber radius. While low charge state ions are magnetized and follow magnetic field lines, HCS ions are collisional in the ECR plasma since their Coulomb ion-ion collision rate is of the order of their cyclotron frequency[8]. Consequently, HCS ions follow a random walk path through the ECR zone leading to a confinement time $\tau \propto r_{ECR}^2 L$, r_{ECR} and L being the ECR zone radius and length. Thus, a longer confinement time increases *de facto* the probability of HCS ion production.

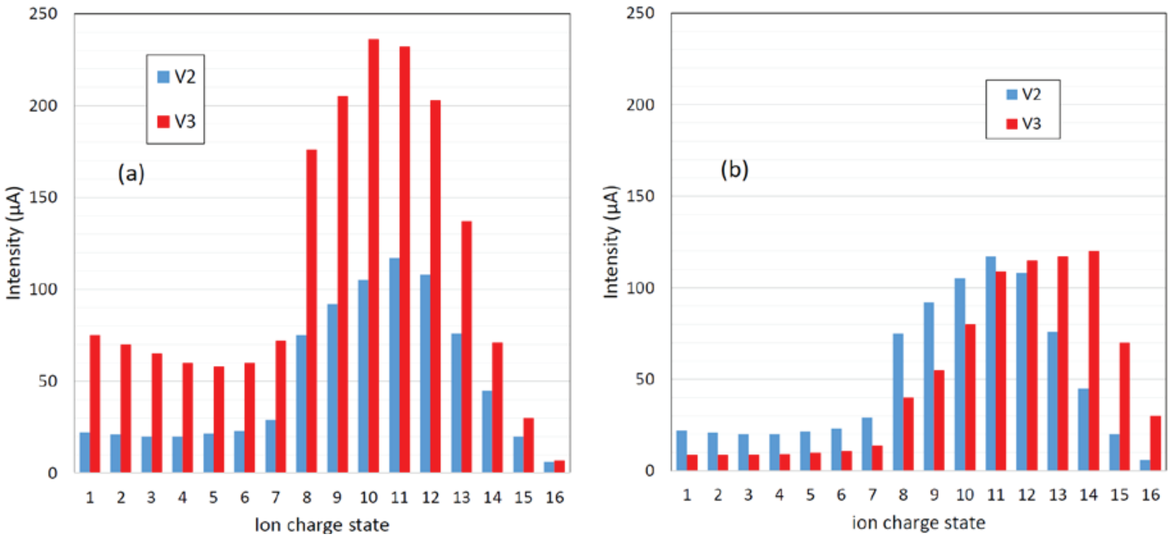

FIGURE 2. (a) Best high CSD of argon for PHOENIX V2 (blue) and V3 CSD (red) for similar source pressure. (b) Blue: same V2 CSD as (a). Red: V3 CSD optimized for Ar^{14+}.

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