

6.4 GHz ECR ion source at VECC

G S TAKI, D K CHAKRABORTY and R K BHANDARI

Variable Energy Cyclotron Centre, Department of Atomic Energy, Block-AF, Bidhan Nagar,
Kolkata 700 064, India

Abstract. The 6.4 GHz ECR ion source that was indigenously developed a few years ago has been operating continuously for injecting oxygen and neon beams to the cyclotron since 1997. VEC-ECR is a single stage high magnetic field ion source provided with a negatively biased electron repeller placed on the axis, near the injection mirror point. The supply of cold electrons and use of low mass mixing gas improve the stability of ECR plasma. Very recently, the effect of aluminum oxide coating on the copper plasma chamber wall has been studied. The plasma chamber wall was coated with aluminum by vacuum evaporation method and then exposed to oxygen gas to form aluminum oxide. It was noticed that the process substantially shifts the charge state distribution to the higher charge state with an enhancement of ion current by an order of magnitude. With the aluminized plasma chamber, the VEC-ECR can now produce 12 μA of O^{7+} , 6.5 μA of Ar^{12+} , 1.5 μA of Kr^{20+} and 1.0 μA of Xe^{31+} .

Keywords. ECR ion source; heavy ions.

PACS No. 29.25.Ni

1. Introduction

A two-stage 6.4 GHz ECR ion source was developed in VECC a few years ago [1]. It has undergone several modifications based on magnetic topology [2,3], external supply of cold electrons [4,5] and microwave feed to improve the performance. Initially, 6.4 GHz ECR ion source was designed for two-stage operation to study different aspects of first-stage discharge, related to methods of microwave power feed and overall ion production performance. It had four sets of coils with two magnetic mirrors and individual microwave feeds for the stages. But the advanced physical consideration and experimental experience led the VEC-ECR to start production of multiply charged heavy ions, in three coils-single mirror configuration with a first stage discharge in the gradient resonance magnetic field. It had single radial microwave feed with internal power divider. The second phase of change in the magnetic topology to meet high magnetic field (high- B) operation increased ion currents production from 15 μA to 50 μA for O^{6+} and 3.0 μA to 6 μA for Ar^{11+} .

Very recently, based on the experience in other laboratories [6,7] we studied the effect of aluminum oxide coating as internal electron donor. The high charge state performance of VEC-ECR has been further enhanced by this aluminum oxide coating on the plasma chamber wall. Now, it can produce 6.5 μA of Ar^{12+} and requires comparatively less

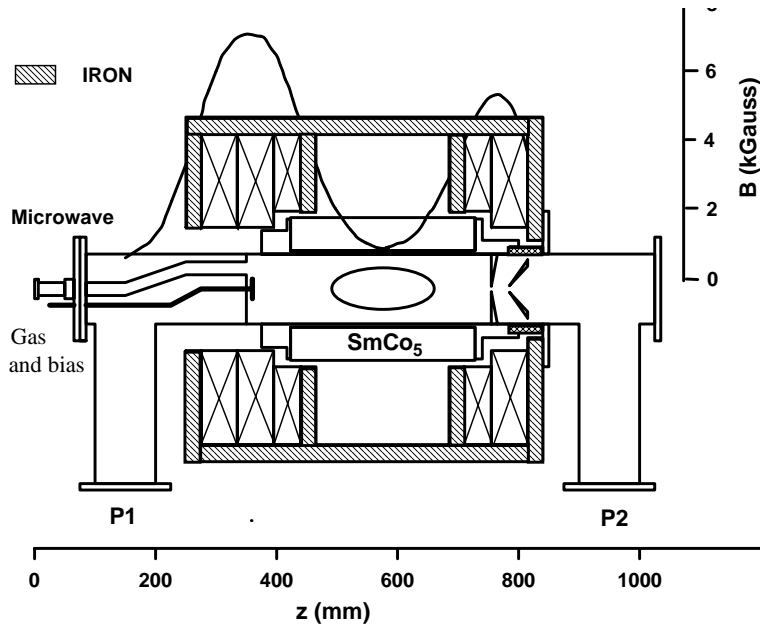


Figure 1. Schematic diagram of VEC-ECR.

microwave power to deliver high charge state ion beam. The long term stability of ion current has been improved remarkably.

2. Description

At present, VEC-ECR is a single stage ion source equipped with a negatively biased electron repeller placed on the axis near the injection mirror point (figure 1). Resonant microwave discharge takes place between two sets of axial coils, isolated by 25 mm thick soft iron plates [8]. The mirror ratios ($= B_{\max}/B_{\min}$) at the injector and extractor mirror points are 6 and 4.5 respectively with a minimum field of 1.1 kG. The main stage plasma chamber is made from oxygen-free high conductivity copper billet. Its inside diameter is 108 mm and length 370 mm. Outside the diameter six slots have been machined out to mount discrete blocks of SmCo_5 permanent magnets of size 50 mm \times 38 mm \times 61 mm having remanent magnetism of about 8.0 kG, magnetized along 50 mm dimension. Special techniques were developed to assemble powerful SmCo_5 magnet blocks on the copper chamber. Each 305 mm long magnet pole was made up of five discrete magnet blocks. Figures 2a and b show a schematic view of the open type sextupole assembly and its field plot. The field diameter of the assembly is 118 mm and can create radial field of 3.4 kG on the chamber wall which is planned to be upgraded by replacing with a stronger sextupole assembly. The axial and sextupolar field calculations were carried out by POISSON and PANDIRA codes. Single axial microwave feed made the gas injection and electron repeller assembly simpler. The indigenously developed high voltage isolator (DC-Cut) and vacuum window are also included in the injection assembly.

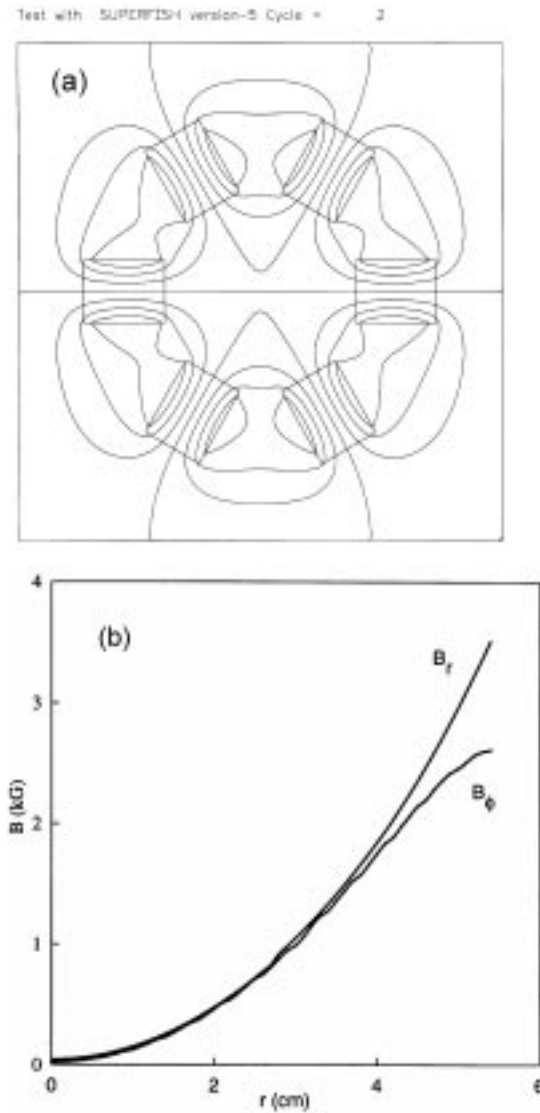


Figure 2. (a) Schematic of sextupole assembly with magnetic field lines. (b) Sextupolar field plot; B_r – field along a radius passing through the pole center; B_ϕ – field along a radius between two adjacent poles.

Heavy ion beam is extracted by an accel/decel extraction system through an 8 mm diameter circular hole. A shaped stainless steel puller electrode is placed 30 mm away from the aluminum plasma electrode and has a 10 mm aperture at the centre. The plasma electrode has been placed at the extraction mirror peak point by a suitable centering arrangement. The bias and puller potentials are +10 kV and –5kV respectively.

The use of low mass mixing gas gives very good result to produce high charge state. The supply of cold electrons from aluminum plasma electrode and biased electron repeller

substantially enhanced the performance of the source. The ratios of mixed-gas to feed-gas vary from 3 to 8 for different ions. The mixing ratio and bias voltage basically depend upon the charge state of a particular element. The typical value of negative voltage applied to electron repeller lies between 50 to 100 V for optimum ion current. The position of the repeller electrode is also very important for peak performance of the source.

3. Results

The plasma, which is stabilized in *B*-min configuration, has high-energy electrons, which by stepwise ionization produce highly stripped heavy ions. The extracted ion current I_q for a charge state q is related to the plasma volume V , ion density n_q and ion confinement time τ_q by the equation [9]

$$2I_q \approx n_q q e V / \tau_q.$$

For a charge neutral plasma

$$n_e \approx \sum_q n_q q$$

where n_e is the electron density. Hence

$$I_q \propto n_e V.$$

So, the presence of higher density of energetic electrons in the plasma is essential for good amount of high charge state extraction.

The higher microwave power (P) under suitable resonance condition creates increased number of energetic ionizing electrons (n_e).

$$P \propto V n_e T_e / \tau_e$$

where T_e , V and τ_e are electron temperature, plasma volume and electron confinement time respectively.

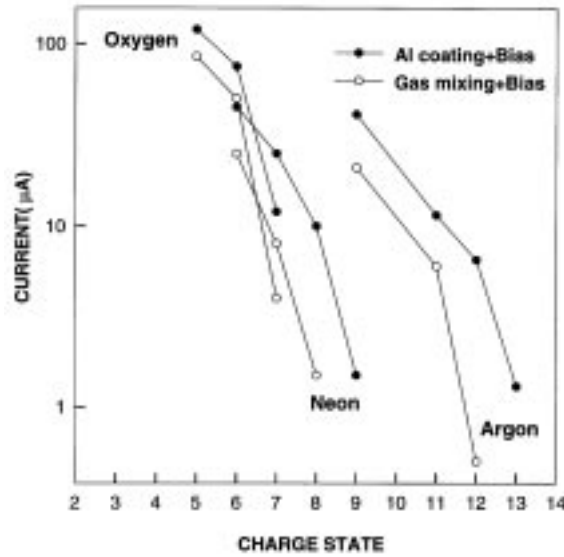
But after a certain level, the ion current does not increase with the microwave power due to starvation of cold electrons in case of a multiply charged ECRIS working at very low gas pressure. Supply of auxiliary cold electrons either from internal or external sources are therefore essential. Internal electron sources are found to be more efficient, e.g., (1) negatively biased disc and (2) wall coating with high secondary electron emission coefficient.

We have already achieved remarkable improvement in the first phase, using aluminum plasma electrode and negatively biased repeller disc. Recently, we studied the effect of aluminum coating on copper plasma chamber wall. Based on vacuum evaporation method, a suitable demountable set-up has been fabricated for periodically applying a coating on the inner wall of the chamber. The coated chamber is then exposed to pure oxygen for a few hours to develop layers of Al_2O_3 .

After the above process, beams of different gases were tried systematically. A drastic improvement in intensity and stability was observed in all the cases. It was noticed that this process enhanced the ion currents almost by an order of magnitude for higher charge states (table 1). The effect of negatively biased electrode remained unchanged but the gas mixing was found to be no more effective. However, in the case of higher charge states of xenon a small amount of mixing gas was found to be helpful.

Table 1. Comparison of currents in μA .

Charge state	Gas mixing+bias	Al-coating+bias
O^{6+}	50	75
O^{7+}	4.0	12
Ne^{7+}	8.0	25
Ne^{8+}	1.5	10
Ar^{11+}	6.0	11.5

**Figure 3.** Comparison of charge state distribution with and without aluminum coating.**Table 2.** Currents for VEC-ECR in μA .

Ion	Current	Ion	Current	Ion	Current	Ion	Current
N^{4+}	130	Ne^{9+}	1.5	Kr^{17+}	9.0	Xe^{24+}	2.5
N^{5+}	86	Ar^{9+}	41	Kr^{18+}	8.5	Xe^{25+}	2.2
N^{6+}	31	Ar^{11+}	11.5	Kr^{19+}	6.5	Xe^{26+}	2.0
O^{5+}	120	Ar^{12+}	6.5	Kr^{20+}	1.5	Xe^{27+}	1.9
O^{6+}	75	Ar^{13+}	1.3	Xe^{19+}	4.0	Xe^{28+}	2.0
O^{7+}	12	Kr^{12+}	45	Xe^{20+}	4.0	Xe^{29+}	1.1
Ne^{6+}	45	Kr^{13+}	20	Xe^{21+}	4.1	Xe^{30+}	1.0
Ne^{7+}	25	Kr^{15+}	10.6	Xe^{22+}	2.6	Xe^{31+}	1.0
Ne^{8+}	10	Kr^{16+}	—	Xe^{23+}	3.6	Xe^{32+}	0.3

From figure 3, it is clear that Al deposition shifted the charge state distribution (CSD) of oxygen, neon and argon towards the higher side. As the secondary electron emission coefficient of Al_2O_3 is sufficiently high (≈ 9), this shift of the CSD may be due to the enhanced supply of transverse cold electrons which lowers the ECR plasma potential [6].

Al deposition allows the ECR to operate at a lower neutral pressure and the consumption of sample gases is also very low. During this period we have developed Kr and Xe beam (table 2) for the first time. With aluminized plasma chamber VEC-ECR produced $1.5 \mu\text{A}$ of Kr^{20+} and $1.0 \mu\text{A}$ of Xe^{31+} satisfactorily.

All currents are extracted at 10 kV through 8 mm circular aperture and optimized for individual charge states. For krypton and xenon, ion currents are measured on the Faraday cup using an image slit of width 5 mm. For the rest of the elements the slit width has been increased to 20 mm.

4. Conclusion

For VEC-ECR, the present μ -wave window cooling restricts the injected μ -wave power up to 600 W. The existing μ -wave window will be replaced by suitable water-cooled one in near future, which will facilitate production of more ion currents of high charge states for heavier elements with higher microwave power. Due to the high erosion resistance of Al_2O_3 against plasma etching, the recycling of aluminum deposition is necessary after an interval of 8 to 10 weeks of continuous operation.

References

- [1] D K Bose, G S Taki and R K Bhandari, *Indian J. Phys.* **B66**, 629 (1992)
- [2] G S Taki, P Y Nabhiraj, R K Bhandari and D K Bose, *Proc. 4th National Seminar on PATPAA*, Calcutta (1996)
- [3] T A Antaya and S Gammino, *Rev. Sci. Instrum.* **65**, 1723 (1994)
- [4] G S Taki, R K Bhandari and D K Bose, *Proc. DAE Symp. on Nucl. Phys.* **B35**, 468 (1992)
- [5] G Melin *et al*, *Proc. 10th Int. Workshop on ECR Ion Sources* ORNL conf-9011136 (1990)
- [6] Z Q Xie and C M Lyneis, *Rev. Sci. Instrum.* **65**, 2947 (1994)
- [7] T Nakagawa, T Kageyama, M Kase, A Goto and Y Yano, *Jpn. J. Appl. Phys.* **32**, 1335 (1993)
- [8] G S Taki, D K Bose, P Y Nabhiraj and R K Bhandari, *Indian J. Pure Appl. Phys.* **39**, 41 (2001)
- [9] G Melin and A Girard, in *Accelerator-based atomic physics techniques and applications* edited by S M Shafroth and J C Austin (American Institute of Physics, New York) p. 36