

# Upgrade of ECR ion source using plasma cathode method

Yasushige Yano  
Cyclotron Laboratory

Plasma cathode method has been newly developed to greatly improve performance of an ECR (Electron Cyclotron Resonance) ion source. This method enables extraction of high current beams of highly-charged heavy ions from the 10 GHz ECR ion source used for the AVF cyclotron.

Ion-acceleration energies attainable by cyclotrons become higher in proportion to the square of charge states of ions; thus, as an ion source installed in a cyclotron is capable of yielding higher charge states, the ion-acceleration performance is dramatically upgraded. For this reason, vigorous efforts have been made to realize a novel heavy-ion source producing high-current highly-charged ion beams.

An ECR (Electron Cyclotron Resonance) ion source, which was invented in 1970's by Geller et al.,<sup>1)</sup> is the most advanced in high productivity of highly charged ions of a wide mass range, good stability, longevity and easy operation. At present various types of ECR ion sources are in widespread use not only for cyclotrons but also for other heavy-ion accelerators.

## 10 GHz ECR ion source for the AVF cyclotron

The injector AVF (Azimuthally Varying Field) cyclotron of the RIKEN Ring Cyclotron is also equipped with an ECR ion source, the picture of which is displayed in Fig. 1. This source consists of two stages as illustrated in Fig. 2. A 10 GHz microwave is fed into both stages to generate ECR-discharge plasma. Highly charged ions are produced in the second-stage plasma, which is magnetically confined transversally by a sextupole field as well as axially by a solenoid mirror field.

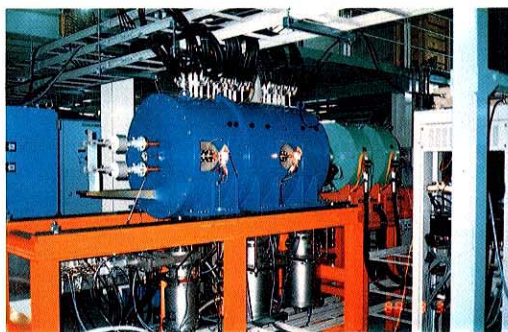


Fig. 1. Photograph of the 10 GHz ECR ion source used for the AVF cyclotron.

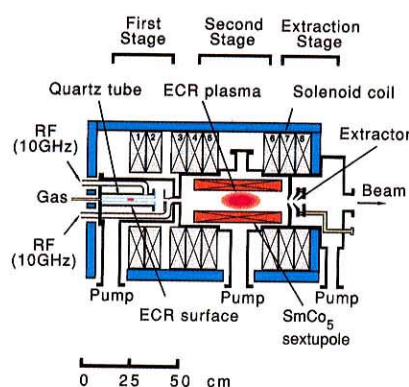


Fig. 2. Cross-sectional view of the original structure of the 10 GHz ECR ion source.

## Efforts to upgrade ECR ion sources

It is well known that highly-charged ions are efficiently yielded mainly through the successive ionization process.<sup>2,3)</sup> Therefore, in order to obtain higher beam currents of highly-charged ions from the ECR ion sources, it is crucial to enrich electron density in the plasma and to prolong exposure time of ions in the electron cloud of high temperature. Very recently, several methods have been successfully introduced for enriching the electron density: (1) an electron gun is used in place of the first stage to supply a high current of electrons into the second-stage plasma;<sup>4)</sup> (2) a negatively biased electrode is positioned in the first stage or in the second stage<sup>5-7)</sup> to push or to repel electrons into the second-stage plasma.

We investigated the performance of the 10 GHz ECR ion source when we set a negatively biased electrode in the first stage.<sup>6)</sup> Considerably good results were obtained from the intensity point of view, but the life-time was limited to about a few months by wearing out of the electrode due to sputtering by ion bombardment. In addition, when a higher microwave power was fed to further increase output beam intensity, the beam intensity became unstable because of a sparkover in the first stage.

## Plasma cathode method

In an attempt to overcome these drawbacks, we introduced the so-called plasma cathode method<sup>8)</sup> to the first-stage structure<sup>9)</sup> as shown in Fig. 3. The first stage is electrically isolated from the second stage; a negative bias voltage is applied between them. Gas is fed into the first stage and then diffused into the second stage. No microwave power was fed into the first stage, since cold ECR-discharge plasma was generated therein by microwaves leaking back from the second stage. In this structure, without the electrode, a potential difference produced between both stages extracts electrons from the first-stage and supplies them to the second one.

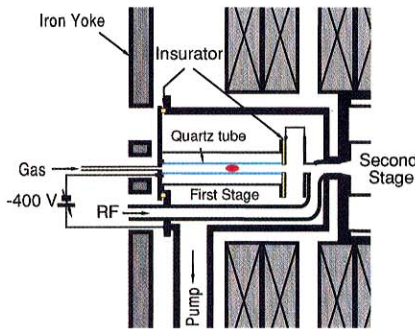


Fig. 3. Cross-sectional view of the first stage modified into the plasma cathode structure.

Figure 4 summarizes the improvement of the ECR ion source performance upon adopting the plasma cathode method for

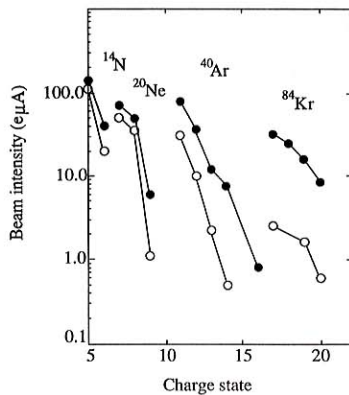


Fig. 4. Beam currents of typical gaseous ions as a function of the charge states. Open circles indicate the best records before using the plasma cathode method. Closed circles are the best records when using the plasma cathode method. Microwave power fed into the second stage was 800 W. The extraction voltage was 10 kV.

typical gaseous ions, as compared with the original records. The increase can be explained in terms of two factors described below, both of which are presumably caused by the efficient supply of electrons into the second-stage plasma from the plasma cathode. Firstly, the efficient electron supply enriches the electron density in the plasma. Secondly, it reduces the vacuum pressure necessary to stably maintain the ECR discharge, resulting in the reduction of charge exchange loss with neutrals and the increase of the electron temperature in the plasma. In fact, the optimum pressures in the plasma chamber were lowered approximately by one order of magnitude, as compared with the original structure. Moreover, the data show that the plasma cathode method is much more effective for higher charge states. This suggests that higher vacuum, as well as higher electron density and temperature, is crucial in obtaining highly charged ion beams.

In summary, we modified the 10 GHz ECR ion source for the AVF cyclotron by introducing the plasma cathode method to the first-stage structure, and tested its performance for typical gaseous ions. It has been confirmed that this method has several advantages as described below. The maximum beam intensities have been greatly enhanced, such as 80 eμA Ar<sup>11+</sup>. At present this intensity is the world-record produced by the 10 GHz ECR ion sources. A very stable operation has been realized; sparkovers are dramatically suppressed during the operation. The life-time is basically infinite, because there is no wear in this structure. The operational vacuum pressure in the first-stage can be so low that the gas consumption rate becomes very small. This is very advantageous, when we use an expensive gas such as an enriched isotope gas. By using this method, intense heavy-ion beams have been extracted, and accelerated by the AVF-Ring cyclotron complex.

## References

- 1) S. Bliman, R. Geller, W. Hess, and B. Jacquot: IEEE Trans. Nucl. Sci. **NS-19**, 200 (1972).
- 2) Y. Jongen and C. Lyneis: in *The Physics & Technology of Ion Source*, edited by I. G. Brown (Wiley Int. Pub., New York, 1989) p. 207.
- 3) A. Muller, E. Saizborn, R. Frodl, R. Becker, H. Klein, and H. Winter: J. Phys. **42**, 1247 (1981).
- 4) Z. Q. Xie, C. M. Lyneis, R. S. Lam, and A. Lundgren: Rev. Sci. Instrum. **62**, 775 (1991).
- 5) G. Melin et al.: Proc. 10th Int. Workshop on ECR Ion Sources, Knoxville, 1990 (Oak Ridge National Laboratory, Knoxville, 1991) p. 1.
- 6) T. Nakagawa and T. Kageyama: Jpn. J. Appl. Phys. **30**, L1588 (1991); T. Nakagawa, T. Kageyama, M. Kase, A. Goto, and Y. Yano: *ibid.* **31**, L1129 (1992).
- 7) S. Gammino, J. Sijbring, and A. G. Drentje: Rev. Sci. Instrum. **63**, 2872 (1992).
- 8) Y. Matsubara, H. Tahara, S. Nogawa, and J. Ishikawa: *ibid.* **61**, 541 (1990).
- 9) T. Nakagawa, T. Kageyama, M. Kase, A. Goto, and Y. Yano: Jpn. J. Appl. Phys. **32**, L1335 (1993).