Cocktail Beam Acceleration Technique at JAERI AVF Cyclotron (II)

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Abstract

At the JAERI AVF cyclotron, an cocktail beam acceleration technique by means of RF frequency change is used for ions with mass to charge ratios (M/Q) nearly equal to 4 and 5 in routine operation. In case of M/Q≅4, mass-to-charge ratio difference between species are comparable to or less than a value of separation limit defined by the M/Q resolution of the cyclotron. This makes it difficult to separate ion species with the cyclotron. In order to purify the cyclotron beam, methods of applying lower dee voltages, frequency shift from the optimum values or injection of beams of a single ion species were examined. A gas feed system of an ECR ion source was modified to produce beams of a single ion species and to reduce gas changing time. The M/Q≅2 cocktail ions were successfully accelerated using those methods recently.

1. Introduction

"Cocktail beam" is mixture of ion beams of plural species, which is usually produced with an ECR ion source. In the technique of cocktail beam acceleration, cocktail ion beam are injected into the cyclotron, accelerated simultaneously and extracted separately. Ion species are selected by slightly changing the RF frequency or the magnetic field. The primary advantage of this technique is to enable us to change ion species and beam energy in short time. Requirements of the cocktail beams have increased as beam applications have been diversified in research field of materials science and biotechnology. Ranges required in beam energy and ion species are increasing as well.

Cocktail ions with M/Q≅5 can be separated by the cyclotron simply by changing the RF frequency and they have been supplied to research experiments since 1998.

In the development of the cocktail beams acceleration with M/Q=4 using ions of $^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$ ions, $^{12}C^{3+}$ and $^{20}Ne^{5+}$ were observed in the beams optimized for the $^{16}O^{4+}$. The M/Q difference, $\Delta(M/Q)/(M/Q)$, of $^{12}C^{3+}$ and $^{20}Ne^{5+}$ from $^{16}O^{4+}$ are 3.2×10^{-4} and 0.6×10^{-4}, respectively (see Table 1). The reason of the intermixture is that they are comparable to or less than separation limit of the cyclotron of about 3×10^{-4} which was experimentally and theoretically estimated[1].

In order to improve the M/Q resolution of the cyclotron, lower dee voltages, intentional shift of the RF frequency from the optimum value were examined [1,2]. In order to make the best use of quick change capability of the cocktail beam acceleration, we also adopted injection of a single ion species. A gas feed system of an ECR ion source (OCTOPUS) was modified to change gases in several minutes for this purpose. By using more than one methods of low dee voltages, frequency change and the new gas feed system, $^{12}C^{3+}$ and $^{20}Ne^{5+}$ beams can separate from $^{16}O^{4+}$.

The paper reports the modification of the ECR ion source, combined use of methods to improve the M/Q resolution or to reduce intermixture of different ion species in cyclotron beams.

2 Modification of Gas Feed System for ECR Ion Source

Injection of a single ion species into the cyclotron is one of the ways to purify cyclotron beam without improving the M/Q resolution. The key to this purpose is reduction of time to change gases. Our ECR ion source, OCTOPUS, has a big gas feed system with 14 gas cylinders mounted in three cabinets. Pressure regulators and pneumatic valves are placed close to the cylinders. Gas change is remotely made with the pneumatic valves. The length of tubes between the pneumatic valves and the leak valves were originally about 3 m. Because of the long tubes and the large volume in them, it took more than an hour to satisfactorily evacuate a gas from the tubes. In the new design, the pneumatic valves were moved on a high voltage board , on which the leak valves are mounted, and the tube length was reduced to 35 cm. The schematic design of the new gas feed system is shown in Fig. 1. After this simple modification, the gases can be changed in several minutes.

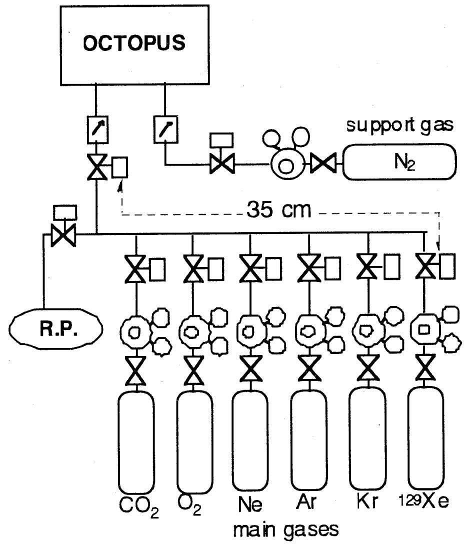

Fig. 1 Schematic drawing of the new gas feed system of the ECR ion source.

Nitrogen, which has M/Q values sufficiently different from 4, is used as a common support gas to save time for purge in the tubes. In every change of gases, evacuating the previous gas and filling the next gas are done in turns two times each. This operation takes only about 7 minutes.

The ions of $^{12}C^{3+}$ are produced from CO_2 gas. Therefore a comparable amount of $^{16}O^{4+}$ ions are injected into the cyclotron with $^{12}C^{3+}$. If we use another gas without oxygen, oxygen ions will be considerably reduced. However, oxygen ions are always observed in beams from the ion source, which are probably produced from water and air leak of the chambers. For this reason, additional methods described in the next section are necessary to obtain $^{12}C^{3+}$ or $^{20}Ne^{5+}$ beams free from $^{16}O^{4+}$.

3 Methods to Improve M/Q Resolution

We use two methods to improve the M/Q resolution; 1) lowering dee voltages than those of regular operation, 2) shifting the RF frequency from the values optimum for a specific ion species. Each method causes increase of turn number of ions to reach the extraction radius. Ions which do not satisfy isochronous condition will phase-out if increase of the turn number is sufficient. Details of the principles and the test operations are reported in Ref. 1 and 2.

We use the method 1) in practical cocktail acceleration for M/Q≅2 and 4 because it is more effective.

4 Use of Isotope for Larger M/Q Difference

Ions of $^{84}Kr^{21+}$, a member of M/Q≅4 cocktail, are produced from a krypton gas. In a pulse height spectrum of cyclotron beams, $^{56}Fe^{14+}$, $^{52}Cr^{13+}$, $^{40}Ar^{10+}$ and $^{36}Ar^{9+}$ are observed as background ions with $^{84}Kr^{21+}$ as reported in the last symposium [3]. The Ar ions may come from impurities in the krypton or nitrogen support gas or from air leak into the ion source. The metallic ions perhaps originate from plasma chamber of the ion source. Elimination of background ions is extremely difficult even if we use the methods mentioned above because their M/Q difference from Kr ion is too small. We can use another isotope of Kr because it has many stable isotopes. The M/Q value of $^{78}Kr^{19+}$ is different enough from the background ions'. Optimization of the frequency to the isotope ion and gas change was made in ten minutes. No background ions were observed in the $^{78}Kr^{19+}$ pulse height spectrum.

5 M/Q≅2 Cocktail Beam Development

A cocktail of M/Q≅2 (fully stripped ions !) is one of the most required ions in the research fields of materials science and biotechnology, since one can use the highest beam energy with the cyclotron for each ion species. The parameters of M/Q≅2 cocktail are listed in Table 1. A new ECR ion source (HYPERNANOGAN) [4] was used in this development since higher performance in production of highly charged ions were required for fully stripped ions.

Fig. 2 shows pulse height spectra for M/Q≅2 cocktail beams measured using a plastic scintillator with the RF frequency changed step by step. For the spectra in Fig. 2-a, mixture of more then one gases of He, CO_2, N_2, Ne and ^{36}Ar were used and the dee voltage values were for non-cocktail acceleration, about 38 kV. As the RF frequency increased, peaks of smaller M/Q ions appeared and peaks of larger ones disappeared. There were more than one peaks in every spectrum because of the insufficient separation. For the other spectra in Fig. 2-b, individual gas was used (N_2 gas was not used in this case) and the dee voltages were lowered by 3 kV. As a result, a single peak of one ion species appeared in each spectrum. A ratio of impurity $^{16}O^{4+}$ in $^{12}C^{3+}$ beam was 0.7 % in this measurement. Fully stripped ions of ^{36}Ar were observed in the spectrum. Its beam was too low to be measured with a Faraday cup and was estimated of the order of 0.1 epA from the count rate and the beam attenuation rate.

Table 1 Parameters of M/Q≅2,4 and 5 cocktail ions.

M/Q	ion	Δ(M/Q)/(M/Q)	RF frequency (MHz)	energy (MeV)
2	$^{4}He^{2+}$		12.448	110
		4.3×10^{-4}		
	$^{14}N^{7+}$		12.454	385
		2.2×10^{-4}		
	$^{12}C^{6+}$		12.456	330
		3.2×10^{-4}		
	$^{16}O^{8+}$		12.460	440
		0.6×10^{-4}		
	$^{20}Ne^{10+}$		12.461	550
		5.3×10^{-4}		
	$^{36}Ar^{18+}$		12.467	990
4	$^{4}He^{+}$		11.908	25
		6.5×10^{-4}		
	$^{12}C^{3+}$		11.916	75
		3.2×10^{-4}		
	$^{16}O^{4+}$		11.919	100
		0.6×10^{-4}		
	$^{20}Ne^{5+}$		11.920	125
		5.5×10^{-4}		
	$^{40}Ar^{10+}$		11.926	250
		1.3×10^{-4}		
	$^{84}Kr^{21+}$		11.928	525
5	$^{15}N^{3+}$		13.867	56
		2.2×10^{-4}		
	$^{20}Ne^{4+}$		13.873	75
		3.2×10^{-4}		
	$^{40}Ar^{8+}$		13.881	150
		0.6×10^{-4}		
	$^{84}Kr^{17+}$		14.047	323

6. Summary

We succeeded in purifying the cyclotron beams of M/Q≅2 and 4 cocktails by applying more than one methods of low dee voltages, RF frequency shift and injection of a single ion species. Use of lower dee voltages or RF frequency shift leads to reducing beam intensity of main ion species as well as impurity ion species. Additional tuning time is necessary to keep beam intensity. As we gain our operational experiences, the tuning time may be shorten. But further development to improve the M/Q resolution, especially for separation of $^{16}O^{4+}$ and $^{20}Ne^{5+}$.

Now we use the injection of a single ion species also for M/Q≅5 cocktails, which simplifies operation of the cyclotron and the ion source.

References

[1] W.Yokota et al., "Cocktail Beam Acceleration Technique at JAERI AVF Cyclotron (I)", this meeting

[2] M.Fukuda et al., "Acceleration of Cocktail Ions at JAERI AVF Cyclotron", PAC99, New York, March 29 (1999), in press

[3] M.Fukuda et al., "Development of Cocktail Beam Acceleration Technique for the JAERI AVF Cyclotron", The 11th Symposium on Accelerator Science and Technology, Harima Science Garden City, (1997) 139

[4] T.Nara et al., "Beam Generation Test for HYPERNANOGAN and Modification of 18 GHz ECR Ion Source at JAERI Takasaki", this meeting

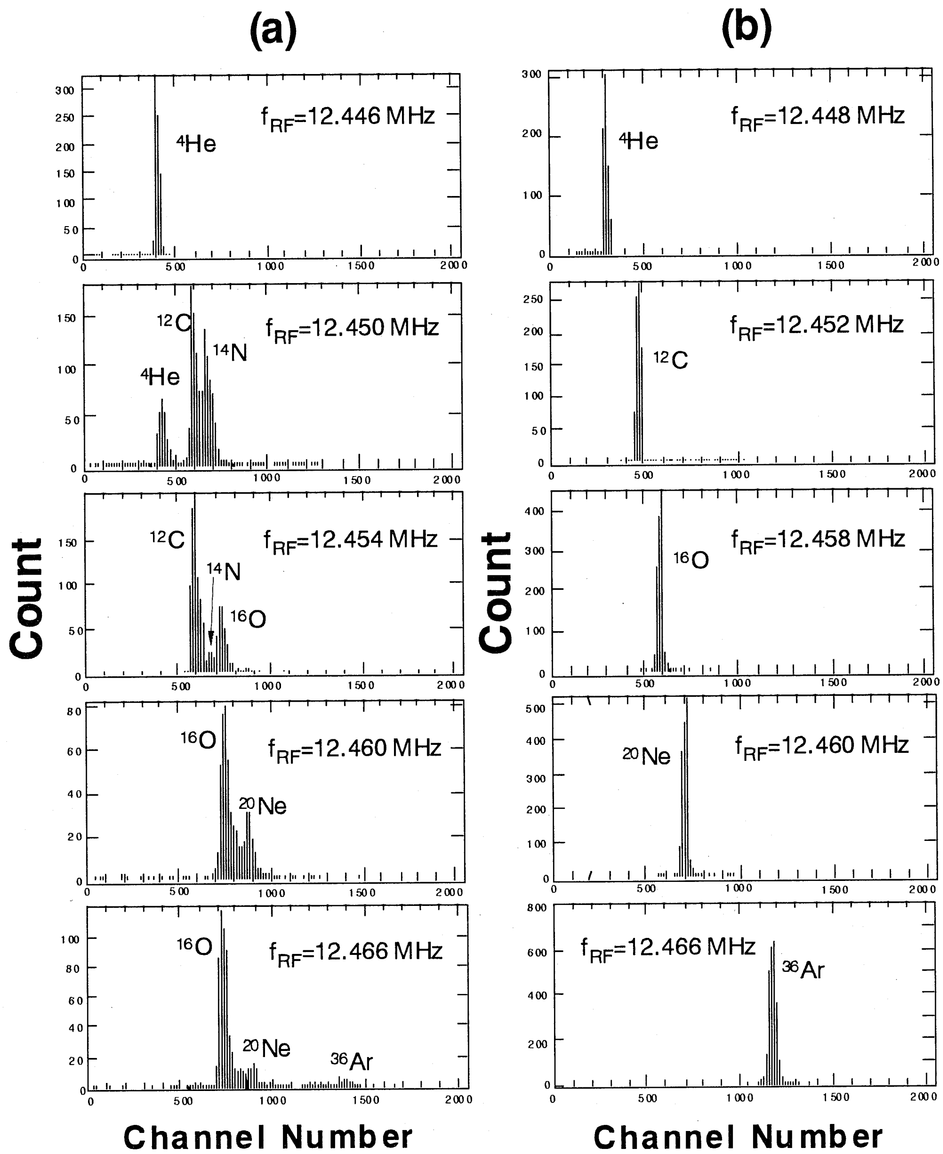

Fig. 2 Pulse height spectra for M/Q≅2 cocktail observed with a plastic scintillator. The RF frequency was changed step by step. In case of a), mixture of plural gases of He, CO_2, N_2, Ne and ^{36}Ar and the dee voltage values for regular acceleration were used. In case of b), individual gas (N_2 gas was not used) and lower dee voltages were used.