RELATIONSHIP OF PERFORMANCE AND RF MODES IN ECR ION SOURCE

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Abstract

The performance of El ectron Cyclotron Resonance (ECR) ion source depends on the operation frequency, the magnetic mirror field, the hexapole fields, the m irror ratio, the ECR zone. We studied the relationship of performance and operation frequency in ECR ion source. The performance (beam intensity of Ar^{9+} ion) was measured according to change of frequency from 9.7 to 11.7 GHz in fixed magnetic field of a new ECR (FM-ECR) ion source. We measured resonant frequencies of plasma chamber of th e FM-ECR ion source in condition of no plasma (current of mirror coils is zero). The data of intensity of Ar^{9+} related to measured resonant frequencies. Their resonant modes were checked with a 3D electromagnetic simulator. As a result, it becam e clear that the performance of the i on source depends on electric field distribution of the RF resonant mode.

INTRODUCTION

We studied new ECR (Electron Cyclotron Resonance) ion source for production of full stripped heavy ion. This type ECR i on source is operated by high e nergy electron which is acce lerated by sa me principle of frequency modulated (FM) Cyclotron. Thi s ion source is named FM-ECR ion source. In experiment with this ion source, we fund that current of higher charge state ions depends on frequency of micro-wave. This phenomena is not so good for production of high energy electron in the FM-ECR ion source by input micro-wave power depending on frequency. Therefore an aim of FM-ECR ion source was not succeeded. Then, measurement of fre quency dependence for production of high charge ion started with the FM-ECR ion source. Performance of ECR ion sources depends on the operation frequency, the magnetic field, the hexapole field, the mirror ratio, the magnetic profile and the length, surface and volume of ECR zone . Characteristic of RF modes in ECR ion source were not studied before for very complex mode. Simple RF modes were studied previously by LBL and C atania [1-3]. The relationship of frequency tuning and RF mode are studying several in stitute [4-6]. We studied relation of between currents of high charge ion and frequency of RF mode using the FM-ECR ion source.

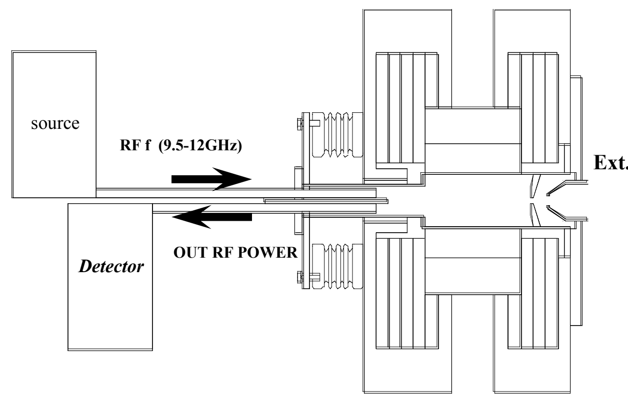


Figure 1: Experimental Apparatus and FM-ECR ion source.

Table 1: Main Parameters of FM-ECR Ion Source

	HiECR (Previous)	Present Status
Microwave Power source		
Frequency (GHz)	10-18	10-12
Power (W)	250	100/250
RF injection port	1	2
Diameter (mm) of Plasma Chamber		
RF injection side	38	
Extraction side	72	
Length (mm)		
RF injection side	77.5	
Extraction side	173.5	
Total length	251	
Hexapole Magnet		
Field on chamber (kG)	11.4	
Material	42N	
Inner diameter (mm)	76-82	
Length (mm)	145	
Mirror Field		
Maximum field on axis (kG)	9.6	7.8
Maximum coil current (A)	600	425
Maximum power (kW)	60	30

ISBN 978-3-95450-123-6

FM-ECR ION SOURCE AND EXPERIMENTAL APPARATUS

The FM-ECR ion source is a miner change from HiECR ion source [7-9]. The FM-ECR ion source and experimental apparatus are shown in Fig. 1. Two microwave guides (19x9.5mm (WRJ 120)) of upper and lower side were connected flange of RF in jection. The flange has a quartz tube of gas feed in center.

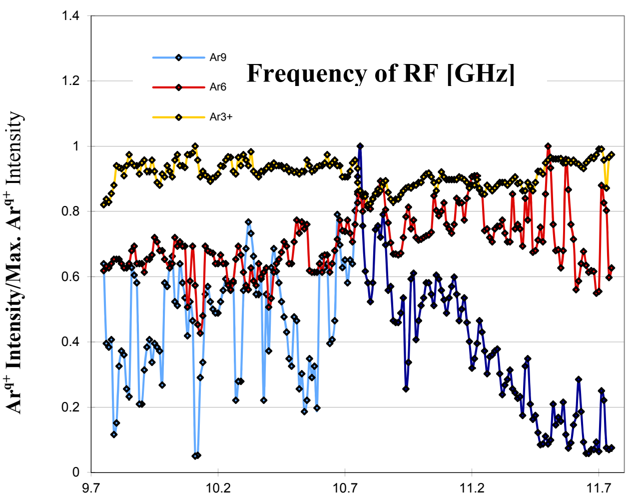


Figure 2: Ar^{q+} Intensity vs RF frequency (Ar^{q+}intensity (*normalized by maximum c urrent, respectively*) vs RF frequency).

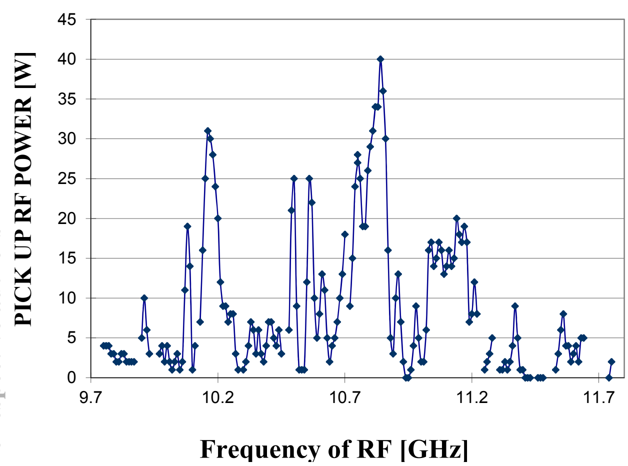


Figure 3: Measured pick up voltage strength of plasma chamber vs RF frequency.

(Measured beam intensity of Ar^{9+} (normalized by maximum current (peak4)) and resonance strength power (W) (normalized by maximum power (peak9)) of plasma chamber vs RF frequency.)

The RF power from microwave power source was transported with the upper waveguide. In resonant frequency measurement without plasma, the lower wave-guide was used as electro-magnetic pick up of the plasma coupler of microwave amplifier. Main parameters of this ion source are shown in Table 1. The e xperiments were studied in mirror coils condition of about 10.7 GHz operation.

EXPERIMENT AND DATA

Beam intensity of Ar^{9+}, Ar^{6+} and Ar^{3+} were measured according to change of frequency from 9.7 to 11.7 GHz produced by microwave amplifier from CPI Company in fixed magnetic field operation of the FM-ECR ion source

by magnetic analyser. These data are shown in Fig. 2. The frequency deference of intensity is increased according as higher charge-state of Ar ion. Inte nsity of Ar^{9+} ion has many resonance peaks. This phenomena is very interesting problem. Output RF power of CPI amplifier depends on reflected power of plasma chamber and control it self. Th is control is v ery complex. Therefore, we measured again beam intensity of Ar^{9+} ion using microwave amplifier of Xicom Company which gives constant output power. Beam intensity of Ar^{9+} is shown inside of Fig.3. The experiments were st udied in mirror coils condition of about 10.7 GHz operation.

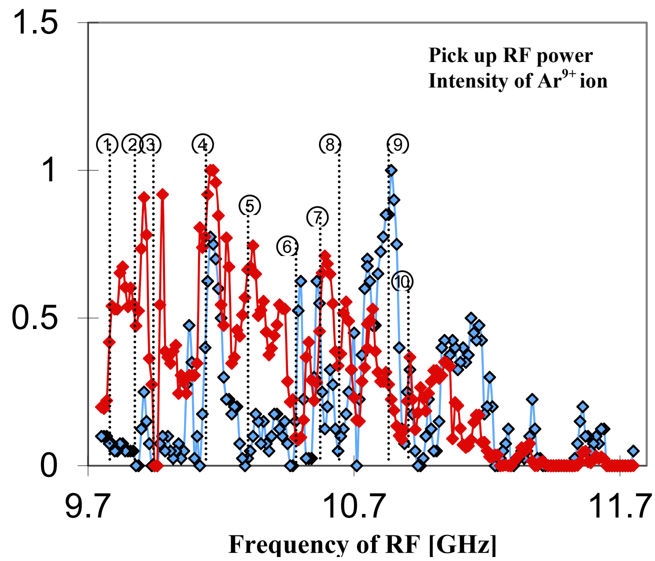


Figure 4: Measured Beam intensity of A r^{9+} and Pick up voltage strength of plasma chamber vs RF frequency.

This phenomena is v ery interesting problem. Therefore, resonant frequency of the plasma chamber of FM-ECR ion source was measured without plasma (zero current ofmirror coils) by two wave-guide system as shown in Fig.1. RF power of 100 W from Xicom

ISBN 978-3-95450-123-6

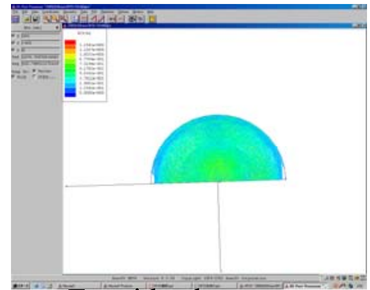
amplifier transported to chamber with upper wave-guide. And the pick-upped power with lower wave-guide is detected by directional-coupler of RF source. This RF pick-up method is ordinal measurement of RF characteristics of linear accelerator cavity. The value of pick-up means resonant strength of empty cavity of ECR ion source. Measured data are shown inside of Fig. 3. These resonant peaks are not same peaks of Ar^{9+} ion current. The intensity of Ar^{9+} ion and pick up RF power are in Fig. 4 on same frequency axis. Typical peaks of intensity of Ar^{9+} and resonance strength of plasma chamber are labeled peak number for data analysis. Resonant peak of RF modes mean that electromagnetic field of the peak is high on constant injection RF power. Their resonant modes were checked with a 3D electromagnetic simulation (High Frequency Structure Simulator (HFSS)) program.

COMPARISON OF COMPUTER SIMULATION OF RF MODES AND EXPERIMENTAL DATA

Current intensity of Ar^{9+} and resonant frequencies were measured. But resonant peaks are not same peaks of Ar^{9+} ion current. Their resonant modes were checked with a 3D electromagnetic simulator HFSS(only electromagnetic program without plasma) program. The labeled peaks are assigned compare with electric field distribution of simulated RF resonant mode of near frequency. As a result, it became clear that the performance of the ion source depends on electric field distribution of the RF resonant mode. Numbers of simulated resonance are about 200 in reason from 9.7 to 11.7 GHz.

In labelled peaks, relationship of peaks of Ar^{9+} intensity, pick up RF power and simulated resonant mode are shown in table 2. Characteristic of RF-mode of typical labeled peaks by HFSS calculation are show in Fig.4-6. We can't understand clearly now proof of that these frequency coincide with peaks Ar^{9+} intensity related ECR plasma and RF resonance characteristics of empty chamber. But these frequencies coincide with Ar^{9+} intensity and simulated resonance mode by 3D electromagnetic simulator HFSS program.

A good electric field distribution of the RF resonant mode on ECR zone produces high current ion beams as shown in Table-2 and Fig.4-6. We measured higher Ar^{9+} currents for peaks (2), (3) and (4). The RF resonance strength for peak (4) is good, but for peaks (2) and (3) it is very low.



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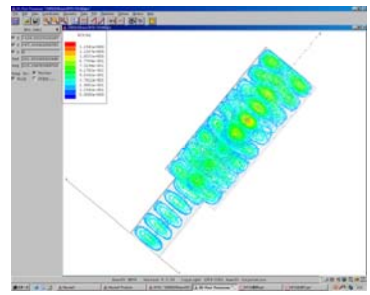

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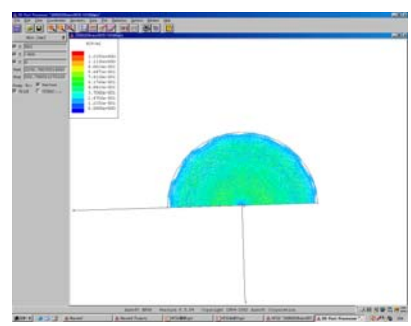
Figure 5: Electric Distribution of (2) HFSS
Detected RF resonance frequency : 9.91[GHz]
Ar9+ intensity peak frequency 9.91 [GHz]
HFSS simulated frequency 9.929[GHz]
Resonant mode:
Injection side:TE_{115}, Extraction side:TE_{115} and TE_{128}



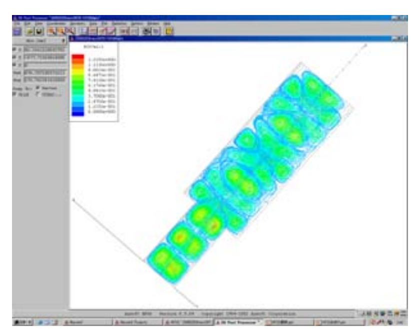
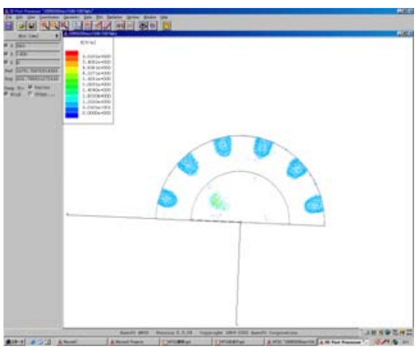


Figure 6:Electric Distribution of (4) HFSS
Detected RF resonance frequency : 10.16[GHz]
Ar9+ intensity peak frequency 10.165[GHz]
HFSS simulated frequency 10.166[GHz]
Resonant mode:
Injection side:TE_{013} Extraction side:TE_{01n} and TE_{02n}

ISBN 978-3-95450-123-6

We think that resonance mode TE_1 or TE_2 of peaks (2) and (3) are better compared by resonance mode TE_0 of peak (4) for effective acceleration of electron (energy and intensity). If a plasma chamber having high resonance-strength similar resonance mode of peaks (2) and (3) is made, making ECR ion source of best performance will be succeeded input RF power of frequency of resonance mode TE_1 or TE_2. Best performance of ECR ion source must have two conditions (frequency of good electric field distribution of the resonance mode and high resonance-strength of plasma chamber). But above reason, good electric field distribution of resonance mode is more important condition. Therefore, peak (9) is not good performance as shown in Fig.3 and Fig.6.



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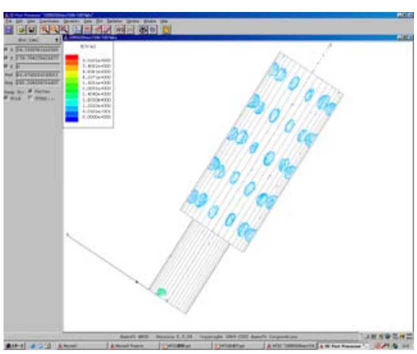

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Figure 7: Electric Distribution of (9) HFSS
Detected RF resonance frequency :10.84[GHz]
Ar9+ intensity peak frequency 10.82[GHz]
HFSS simulated frequency 10.874[GHz]
Resonant mode:
Injection side: no resonance Extraction side:TE_{614}

Table 2: Relationship of Peaks of Ar^{9+} Intensity, Detected RF Power and Characteristics of Resonance Modes

Peak(N)	f(GHz)	Detected Pow.(W)	Ar^{9+} $e10^{-6}$A	1st ECR zone	Inj.cham. RF Mode	Ext. cham RF Mode
I	9.83	3	3.3	Yes	TE_{012}	TE_{01},TE_{02n}
2	9.92	10	4.45	Yes	TE_{115}	TE_{128}
3	9.97	4	4.5	Yes	TE_{214}	TE_{225}
4	10.16	31	4.9	Yes	TE_{013}	TE_{01},TE_{02n}
5	10.32	7	3.69	Yes	TE_{013}	TE_{025}
6	10.50	25	-	No	-	TE_{419}
7	10.56	25	-	No	-	TE_{614}
8	10.61	13	3.48	Yes	TE_{013}	TE_{026}
9	10.85	40	1.55	No	-	TE_{615}
10	10.91	13	1.8	Yes	TM_{114}	$TM_{12,11}$

SUMMARY

We studied the relationship of performance and operation frequency in ECR ion source. The performance of intensity of Ar^{9+} ion was measured according to change of frequency from 9.7 to 11.7 GHz in FM-ECR ion source. We measured resonant frequencies of plasma chamber of the FM-ECR ion source in condition of without plasma. Their resonant modes were checked with a 3D electromagnetic simulator (HFSS). As a result, it became clear that the performance of the ion source depends on electric field distribution of the RF resonant mode. If these phenomena are true, the resonance strength is strong, but in RF mode of not so good electric field distribution, the intensity of high charge ion is low. Electric field distribution of RF mode (main TE mode) is good and resonant strength is strong, performance of ECR ion source is best. Therefore we will be able to design good performance ECR ion source on these 2 conditions. But this condition depends on ECR zone and magnetic field. We will study relationship of performance, ECR zone and magnetic field.

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ISBN 978-3-95450-123-6