ECR ION SOURCE FOR RIKEN HEAVY ION LINAC

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1. *Abstract*

RIKEN Heavy Ion Linac, RILAC [1], has been operating for ten years with use of a PIG ion source and has been used for studies in atomic physics, solid state physics, radiation and nuclear chemistry, and others. It also is used as an injector for RIKEN Ring Cyclotron [2]. To get higher charge-state ion beams and the large number of ion species, we replaced the PIG ion source by an ECR ion source on the 500 kV injector in the last year. We bought the ECR ion source, NEOMAFIOS [3], from C.E.N.G in France. This ECR ion source should be an ideal source for RILAC injector because it is compact and it consumes less than 10 kW electric power. With this improvement the maximum energies of ions having a mass number larger than 16 are expected about to be twice as large as previously obtained. The performance of this ECR ion source and the beam acceleration are described.

2. *Introduction*

RILAC consists of six quarter-wave resonators with drift tubes loaded at their voltage loop. The resonant frequency has been set according to the charge to mass ratio of the ions. By using that scheme, various ions of differing charge to mass ratio can be accelerated. Operation with wide frequency range (17~ 43 MHz) enables the acceleration of ions with charge to mass ratio from 1/2 to 1/27 and operation under 100 % duty factor.

The electric power is limited to 50 kVA on the 500 kV injector terminal with the ECR ion source installed. A NEOMAFIOS 8 GHz source would be an ideal source for RILAC injector because it is compact and it consumes less than 10 kW electric power owing to the permanent magnets (FeNdB) used for both the hexapole field and mirror field. Table 1 gives some parameters of the NEOMAFIOS. The NEOMAFIOS arrived at our laboratory in March of 1990 and has been tested from April to the middle of August of 1990 on the test bench. Figure 1 shows schematic drawing of the ECR ion source reconstructed on a 500kV electrostatic injector. The beams extracted from this ECR ion source are bent to analyze the charge to mass ratios of ion beams by a 70°magnet having a radius of 350 mm. The two electrostatic quadruple doublets were equipped for the beam focussing.

3. *Performance of ECR ion source*

Table 2 gives ion currents of the NEOMAFIOS. At present we have produced 42 different ion species on the ECR ion source. The NEOMAFIOS displayed quite steady operation in production of gaseous ion beams. For the ion production of "metallic" materials having a high melting point such as Ti, V, Cr, Zr, Nb, Mo, Rh, Ag, Sm, Dy, Ho, Er, Hf, Ta, W, Re, and Ir, we have used a rod of 1 ~ 4 mm in diameter and 50 mm in length. These rods are directly inserted in a plasma axially. For materials such as Fe, Ni, and Co which are ferromagnetic, the samples were made in the form of a twist rod with two wires each 1 mm in diameter in order to overcome bend moments due to the magnetic force and are directly inserted in a plasma. We have used an oxide rod of MgO, Al_2O_3, SiO_2, CaO, Cr_2O_3, NiO, and Y_2O_3 with 3 ~ 4 mm in diameter and 50 mm in length for production of these metal ions. This is a good method for obtaining very stable ion beams over long periods of time. These oxide rods have a high melting point and are directly placed in a plasma. For the production of ions such as Mn, Cu, Zn, Ge, In, Sn, Au, Pb, and

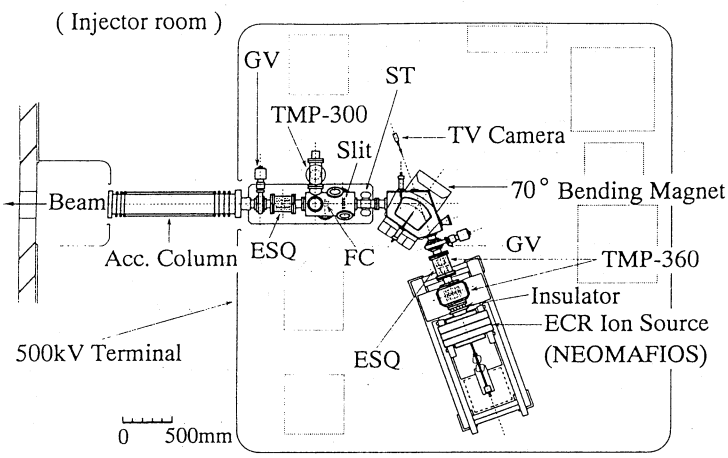

Figure 1. Schematic drawing of the ECR ion source reconstructed on a 500kV electrostatic injector .
ESQ, Electrostatic quadruple doublet; ST, Steering magnet; FC, Faraday cup; GV, Gate valve; TMP, Turbo molecular pump.

Table 1. Parameters of ECR ion source.

Mgnetic parameters	
Permanent magnet type	: FeNdB
Magnetic field on axis	: 0.21 ~ 0.52 T
Electric power	: 0 kW
Microwave parameters	
RF frequency	: 8 GHz
RF power injection	: Axial
RF power	: 1.7 kW (max.)
Power consumption	: 5 kVA
Dimensions	
Chamber diameter	: 66 mm
Chamber length	: 148 mm
Extraction gap	: 45 mm (10 kV)
Source aperture	: 10 mm
Extraction aperture	: 16 mm

Bi the rod technique is not appropriate because the vapor pressure at the melting point of those metals are lower than a required pressure of 10^{-3} Torr. Therefore a small tantalum crucible (4 mm in diameter, 0.3 mm in thickness, and 50 mm in length) was used to contain the sample during heating by plasma. We have also tested to obtain these ions by use of an oxide rod such as Mn_3O_4, Cu_2O, ZnO, GeO_2, In_2O_3, SnO_2, PbO, and BiO_3. Ion currents with these oxide rods except the case of Ge and Pb were very stable compared with a crucible method. Figure 2 shows a charge-state spectrum with tantalum optimized on Ta^{17+} peak. Oxygen was used as support gas.

4. *Beam acceleration*

We reconstructed the ECR ion source, NEOMAFIOS, on the 500 kV high voltage housing of the injector in fall of 1990. After adjustment of the source for one month, the beam acceleration test was done from early of December, 1990. RILAC started to deliver the beam for the users in January of 1991. Machine is operated on 24 hours per day, 5 days per every weeks. We have accelerated 29 kinds of ions represented at inverted number in Table 2. Figure 3 shows the relations among energy per nucleon, frequency, and effective acceleration voltage. The number on each line is M/q, the ratio of the mass to the charge. Figure 4 shows the ion energies from RILAC using the ECR ion source compared with the previous PIG ion source. It is expected that the ion energy with the ECR ion source will be about twice as large as that with the PIG ion source for mass numbers greater than 16. The beam transmission of injection line is typically 30 to 40 % with maximum of 50 %. The overall transmission from the source to the experimental line is typically 30 %. Specially, with this improvement, we are able to accelerate and utilize the multicharged ions of solid elements such as V, Mn, Fe, Co, Zr, Nb, Mo, Ag, In, Sn, Ta, Au, and Bi which could not be produced by use of a spattering PIG ion source.

References

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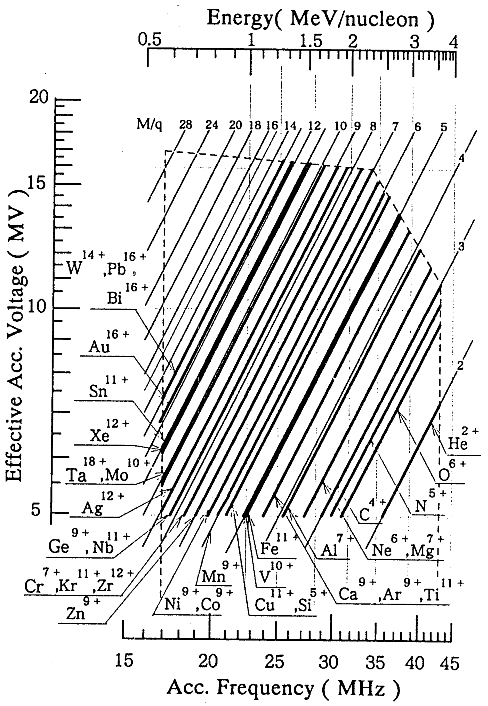

Figure 3. Relations among energy per nucleon, frequency, and effective acceleration voltage.

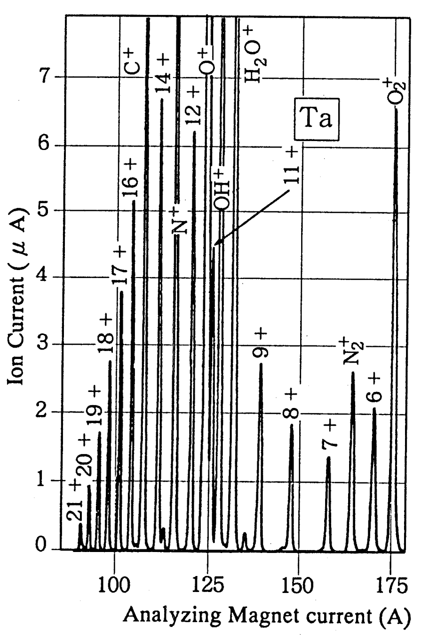

Figure 2. Charge-state spectrum with tantalum optimized on Ta^{17+}peak. RF power, 230W; Beam extraction voltage, 10kV; Support gas, O_2 .

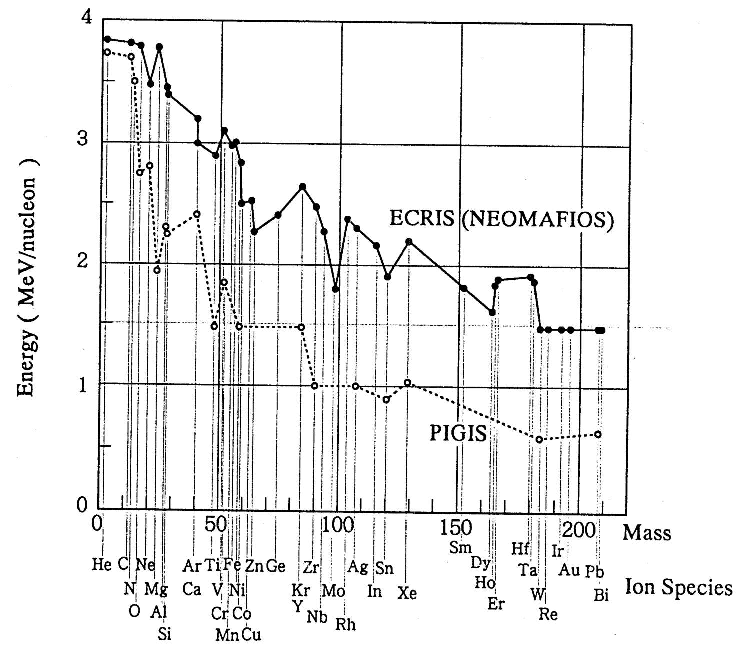

Figure 4. Ion energies from RILAC using the ECR ion source compared with the previous PIG ion source. (Ion current at the ECR ion source ≧ 1 μ A)

Table 2. Ion currents from ECR ion source (μ A).
Inverted number represents the ion accelerated at RILAC.

Isotope	Gas	Charge State																						Remarks
		1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	13+	14+	15+	16+	17+	18+	19+	20+	21+	22+	
^{4}He	He	**500**	210																					
^{12}C	CO_2,He	75	57		**18**	2.3																		
^{14}N	N_2,He	90	**95**	**63**	50	30	2.8																	
^{16}O	O_2	93	85	65		15	6	0.25																
^{20}Ne	Ne,He	215	96	82	**65**		6.5	1.7																
^{40}Ar	Ar,O_2		75	55	50		**30**	24	**26**	10		0.7	0.1											
^{84}Kr	Kr,O_2				17.5	16			17	**11.5**	9	6.8		3.7		1.2		1		0.5				
^{129}Xe	Xe,O_2					11	11	13.5		**10**	6.6		3.8	**3.1**	2.5	2.2		1.3	1.1		0.4			
^{24}Mg	He	45				30		7.5																MgO, ϕ 4, rod
^{27}Al	O_2		22	34	33		**15**	**6**	2															Al_2O_3, ϕ 4, rod
^{28}Si	He			15		**33**				1														SiO_2, ϕ 3, rod
^{40}Ca	O_2		72	70	55		36	27	26.5	25.5		5.5	1											CaO, ϕ 5.7, rod
^{48}Ti	O_2		5.2			15		14			6.5	4.4		0.3										Ti, ϕ 2, rod
^{51}V	O_2		2.5		7.5	12	12	12	10	7.5	**4.8**	2.4	1											V, ϕ 1, 2 rods
^{52}Cr	O_2		9		27	30	32.8	**25.5**	15	8.3	5.8	3.6	2		0.3									Cr, ϕ 2, rod | Cr_2O_3
^{55}Mn	O_2				51	68	60	42	19	9	4	2.6	0.8											ϕ 4, Ta crucible | Mn_3O_4
^{56}Fe	He,O_2					15	15			11.3	8.2	**4.6**	3	1										Fe, ϕ 1, 2 rods
^{58}Ni	He,O_2		4	4.8	**5.2**	8	**12**	13.5	14	11	8		1.7	0.75	0.25									Ni, ϕ 1, 2 rods | NiO
^{59}Co	He		3.6	7	15.6	26	25.6	19	11	6	2.2		2	0.7	0.2									Co, ϕ 1, 2 rods
^{63}Cu	O_2			**9**		**17**	19	17	**15**		6.5	4												ϕ 4, Ta crucible | Cu_2O
^{64}Zn	He			32		35	34	26		8.3	3.3	1.1												ϕ 4, Ta crucible | ZnO
^{74}Ge	O_2		1.8	3		4.3	5.5	6.3	6	4.6	2.6	1.3	0.5	0.27										ϕ 4, Ta crucible | GeO_2
^{84}Y	He			5.4	3.1		2.6	3	4.5	6.6	7.5		5.6		1.1									Y_2O_3, 4 × 4, rod
^{90}Zr	O_2				1		1.7	1.9	2.6	4.2	4.5	5	6.5		2.6		0.8							Zr, ϕ 2, rod
^{93}Nb	O_2			11	19	23	13	9.5	7	7	7	5	3	1.7	0.6									Nb, ϕ 3, rod
^{98}Mo	O_2				3.8	5				3.5	3.5	3		0.65										Mo, ϕ 2, rod
^{103}Rh	O_2			0.5	1.2	2.3		4.1	5.2	8.1	8.9	9.2	8.9		5.7		2.1		0.7					Rh, ϕ 1, rod
^{107}Ag	He			1.2	2.6	5.2		8.4	8.7	9	7.3	6.5	4.9	2.5	1.6	1.2	0.9	0.4						Ag, ϕ 3, rod
^{115}In	O_2			10	21	31	24	22	16	13.5	10.5	7.5	5.3	4.5	3	2	1.2	0.6	0.2					ϕ 4, Ta crucible | In_2O_3
^{120}Sn	He,O_2				3	5.2	5.7		10	7		4.2	2.7	1.8	1		0.2							ϕ 4, Ta crucible | SnO_2
^{152}Sm	O_2				0.4		0.8	1.3	1.8		4.7	5.1	**6**	5.8	5.3	4.9	3.6	2.4						Sm, ϕ 4, rod
^{164}Dy	He,O_2						4	5.1	5.9			6.7	4.9	2.9	2	1.8	1.5	1.1	0.7	0.3				Dy, ϕ 6.3, rod
^{165}Ho	O_2							0.7	1.2		2.5	5.3		**6.4**		6	5	3.9	2.6	1.6	0.6		0.15	Ho, ϕ 1, rod
^{166}Er	He,O_2							2	3	4.3		11		**13.2**		9.5	7.7	5.7	4.1	1.9				Er, ϕ 4, rod
^{180}Hf	O_2							2	2.5	3.7			7.6		**6.6**		4.3	3		1.3	1	0.5		Hf, ϕ 2, rod
^{181}Ta	O_2					8.5		18	19	19		14	12		**8.2**		5.5	5	4.3	3	2	1.1	0.6	Ta, ϕ 1, rod
^{184}W	O_2					0.9	1	1.4	1.7	2.4			4		3		1.5	0.9	0.5	0.2				W, ϕ 1, rod
^{187}Re	O_2					4.8	7	10.6	12	10.5	8.3		4.1	4.3	3.6	2.3	1.8	1	0.6	0.3				Re, ϕ 1, rod
^{193}Ir	O_2							2.9	9.2	10.5	8.5	6.5		5.4	4.8	3.5		1.7	0.9	0.5	0.2	0.1		Ir, 1 × 1, rod
^{197}Au	O_2						13.7		19.2	16.5	13.7		10	6		4.3	4.0	2.6	1.5	0.8	0.4	0.3		ϕ 4, Ta crucible
^{208}Pb	O_2						7.7		13.8	13.3	10.8	8.3			**5.2**		**3.5**		1.7	1	0.5	0.3	0.1	ϕ 4, Ta crucible | PbO
^{209}Bi	He						3.3		8.3	10	**8.7**	7.6	5.6		5.6		3.6	2.3	1.4	0.87	0.45	0.32	0.1	ϕ 4, Ta crucible | BiO_3