89-492

объединенный
институт
ядерных
исследований
дубна

E7-89-492

V.B.Kutner, S.L.Bogomolov, A.A.Efremov,
A.S.Pasyuk, Yu.P.Tretyakov

THE EFFICIENCY OF CONSUMING RARE ISOTOPES IN A PIG ION SOURCE

Submitted to International Conference
on Ion Sources, July 10-14, 1989, Berkeley, USA

1989

Кутнер В.Б. и др. E7-89-492
Эффективность использования редких изотопов
в дуговом ионном источнике

Проводится анализ эффективности использования рабочего вещества при получении и ускорении пучков ионов из дугового источника ионов на циклотронах ЛЯР ОИЯИ в сравнении с результатами для источника ионов с электронно-циклотронным резонансом (ЭЦР) ГАНИЛ (циклотронный комплекс тяжелых ионов в Кане, Франция) и циклотрона в Беркли (США). Представлены экспериментальные результаты, полученные при ускорении на циклотронах У-400 и У-300 пучков ионов редких изотопов (Mg÷Ge). Описаны особенности подачи в циклотронный источник твердого рабочего вещества. Обсуждаются оптимальные условия для эффективного использования рабочих веществ в дуговом разряде. Приведены результаты исследований, получения и ускорения пучков ионов редких изотопов газов, в том числе радиоактивного изотопа углерода-14. Обсуждаются возможности и перспективы развития эффективных источников ионов ЛЯР ОИЯИ для циклотронного комплекса циклотронов У-400 и У-400М.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1989

Kutner V.B. et al. E7-89-492
The Efficiency of Consuming Rare Isotopes
in a Pig Ion Source

The efficiency of consuming a working substance in the cyclotron arc ion source during operation at the LNR JINR cyclotrons is analyzed in comparison with the results obtained for the ECR ion source of GANIL and the Berkeley cyclotron. The experimental results are described, which have been obtained during the acceleration of rare isotopes ion beams (Mg÷Ge) at the U-400 and U-300 cyclotrons. Some features of solid working substances fed into the cyclotron ion source are described. The optimal conditions for the efficient use of working substances in the arc discharge are discussed. The results of producing and accelerating rare gas isotopes ion beams, including the radioactive isotope carbon-14, are presented. Prospects for the future development of efficient ion sources for the LNR cyclotron complex, consisting of the U-400 and the U-400M are discussed.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1989

The accelerated beams of rare and radioactive isotopes are of great interest for heavy ion physics lately [1,2].

However the production of these ion beams requires the use of high-efficiency ion sources. This requirement becomes very important when rare and expensive isotopes, as ^{48}Ca, or radioactive ones, such as ^{14}C, are used. In the case of using, e.g. Be, it is possible to run with a low concentration of working substance if the ion source has a high efficiency.

In the present paper the efficiency of consuming the working substance in the cyclotron arc ion source during operation at the JINR LNR cyclotrons is analyzed in comparison with the results obtained for the ECR ion sources of GANIL and of the Berkeley cyclotron.

At present the PIG ion sources are used at the cyclotrons of the Laboratory of Nuclear Reactions JINR. The successful development of this type of ion source has made it possible to obtain at the cyclotron U-400 intense ion beams (10^{12} - 10^{14} pps) in the range from N^{2+} to Kr^{9+}. Such a source provides beams of multiply-charged gas ions, for example, Ar^{8+}, Kr^{11+} and Xe^{15+}, with intensities of 1.5×10^{13}, 8×10^{11} and 4×10^{11} pps respectively.

In table 1 there are presented the ions produced from solids in the PIG source with cathode sputtering. Most of the ions of the elements of the Mendeleev Periodic Table were accelerated at the LNR cyclotrons.

The main studies with ion sources at the U-400 cyclotron dealt with the production and acceleration of ion beams of enriched isotopes ranging from ^{26}Mg to ^{76}Ge to energies above 6 MeV/n (table 2).

Recently studies aimed at the production and acceleration of the ions of the radioactive isotope ^{14}C have been carried out.

The acceleration of ^{14}C ions is a very difficult technical problem. However, these beams were needed for generation of the heavy isotopes of light nuclei, for example, ^{6}H, ^{7}H, ^{9}He, ^{10}He and other nuclides. Also they are required for the synthesis and study of transfermium elements.

To solve this and other problems of heavy ion physics $^{14}C^{2+}$ and $^{14}C^{3+}$ ion beams were produced using a PIG ion source with $^{14}CO_2$ as a working gas.

Table 1

Solid states ion yield from the PIG source at test operation

Element	Regime: discharge		Regime: sputtering		Gas	Ion yield, mA/peak												Total current		Conditions of analysis	
Z	U_d,V	I_d,A	U_s,V	I_s,A		1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+	mA	%	H,kG	U_{ex},kV
12 Mg	660	7.5	820	1.9	Ar	18	85	32	3.0	0.4	0.06	0.006						140	77	3.6	18
13 Al	300	8.2	980	1.9	Xe	22	59	20	3.4	0.[illegible]6	0.04							105	95	3.8	15
14 Si	620	11	1900	2.5	Xe	12	46	35	13	1,6	0.18	0,018						104	80	3.6	24
15 P	1000	5.3	1000	1.0	Ar	3	6.3	5.5	1.2	0.26	0.03							18	18	3.6	17
20 Ca	600	9.5	540	1.8	Xe	3	23	22	14	4.6	1.0	0.18	0.035					66	80	3.6	17
21 Sc	500	8	1700	0.64	Xe	1,2	18	19	4.9	0.8	0.05	0.01						45	74	3.6	17
22 Ti	750	16	1250	2.4	Xe	2.1	8.5	14	14	8.8	1.1	0.33	0.035					43	43	4.4	22
23 V	900	15	1400	1.6	Xe	6.3	19	13	14	6.4	1.1	0.15	0.03					59	74	4.4	21
24 Cr	1200	15	850	1.0	Xe	3,7	11	5.2	10	8.8	3,3	0.85	0.08	0,008				48	65	4.4	21
25 Mn	650	8.5	800	0.7	Xe	5	16	14	11.3	6.1	1,6	0.39	0.09	0.026	0.001			56	63	4.4	20
26 Fe	480	13	600	1.6	Xe	3	13	14	6.4	1.7	0.33	0.12	0.04	0.004				38	76	5.3	28
27 Co	500	15	790	1.3	Xe	13	19	15	10	2.5	0.83	0.08	0.01	0.008				59	70	3.6	17
28 Ni	800	6	1000	1.0	Xe	–	23	24	16	6.7	1.5	0.44	0.08	0.03				73	60	3.6	17
29 Cu	540	10	400	2.3	Ar	–	30	32	35	26	6.8	1.9						150	70	3.6	17
30 Zn	400	7.5	560	1.6	Xe	–	70	55	29	9.5	3.95	0.76	0.2	0,024				170	93	3.6	15
32 Ge	900	5.5	2000	0.5	Ar	6.4	17	9.8	11	6.4	1.35	0.48	0.09					54	77	3.6	20
34 Se	950	10	500	0.65	Xe	–	3.9	9.5	7.6	5.8	1.35	0.56	0.18	0.01				29	32	5.3	22
40 Zr	1100	5	1100	0.8	Ar	–	6.9	4.1	5.9	3.72	1.41	1.0	0.47	0.15	0.04			24	34	3.6	16
41 Nb	700	20	880	1.6	Xe	0.7	4.8	6.8	11	17.3	3.8	1.1	0.33	0.044	0.004			29	45	4.4	24
42 Mo	380	9.5	940	1.8	Xe	–	24	25	29	16.8	9.4	2.0	0.4					100	90	3.6	16
48 Cd	900	10	200	1.0	Ar	–	14	18	28	37	22	11.3	3	0.74	0.11	0,025		146	90	4.4	20,5
49 In	540	11	1250	0.65	Ar	–	1.7	3.3	6.4	7.4	4.4	3.2	1.2	0.33	0.018			29	65	5.3	26
50 Sn	840	11	650	0.75	Xe	–	1.6	2.6	3.3	2.9	3.0	3.7	1.3	0.13				18	40	4.5	22
57 La	760	11	850	1.1	Xe	–	–	8.5	7.7	7.9	5.5	5.0	3.3	2.0	0.9	0.042		57	57	4.4	20
72 Hf	650	7	750	1.0	Ar	3,9	4,1	3.6	4.5	4.71	2.33	0.6	0.21	0.08	0.01			34	72	5.3	18
73 Ta	470	9.8	970	1.5	Ar	–	–	–	11.4	18.9	12.5	8.4	3.0					54	65	3.6	15
74 W	360	9	980	1.4	Xe	–	–	20	17.1	13.1	6.8	3.3	0.7	0.12				61	65	3.6	15
75 Re	380	20	540	2.8	Ar	–	15	14	12.4	14.3	8.6	6	0.9	0.6				86	66	5.7	18
82 Pb	950	10	500	0.65	Xe	–	–	1.3	4.9	5.5	8.95	8.8	7	3.9	2.1			42	46	5.3	22
83 Bi	860	8.5	480	0.8	Ar	–	–	2.4	2.8	5.6	6.3	4.2	2.0	1.2	0.91	0.28	0.03	30	55	3.6	17
90 Th	1200	10	750	0.9	Ar	–	–	1.6	4.3	8.6	6.8	15	18	18	12	4.8		89	53	5.2	17

Table 2

Ions of the enriched isotopes accelerated at the U-400 cyclotron

Accelerated ion	Working substance	Content of the isotope in a sputtering electrode, atoms/%	Substance after regeneration	The intensity of internal beam, pps
$^{26}Mg^{3+}$	MgO	37	MgO	4.0×10^{13}
$^{48}Ca^{5+}$	CaO	20	CaO	5.0×10^{12}
$^{49}Ti^{5+}$	TiO_2	11	TiO_2	1.0×10^{13}
$^{50}Ti^{5+}$	TiO_2	10	TiO_2	9.6×10^{12}
$^{53}Cr^{5+}$	Cr_2O_3	17	–	6.0×10^{12}
$^{54}Cr^{6+}$	Cr	36	Cr	6.3×10^{12}
$^{58}Fe^{6+}$	Fe	91	Fe	1.0×10^{13}
$^{64}Ni^{6+}$	Ni	78	–	3.5×10^{12}
$^{70}Zn^{8+}$	Zn	45	–	4.0×10^{11}
$^{76}Ge^{8+}$	Ge	74	–	1.0×10^{12}

Since $^{14}CO_2$ is a radioactive gas, a hermetically-sealed feed and recover gas system has been designed to avoid the leakage of the radioactive gas.

Special investigations have been done to determine the optional working gas consumption. The consumption was decreased to about 0.03 cm^3 per minute for Ar as a supporting gas.

Bearing in mind that the main experiments to produce and accelerate rare and radioactive ion beams in the world's cyclotron laboratories were performed with PIG and ECR ion sources, the efficiencies of consuming some working substances in such ion sources is compared in Fig. 1 and in table 3 /1-9/.

The efficiencies of consuming a working substance in the cyclotron multiply charged ion source and during acceleration in cyclotrons is made using Green's method /10/, used for singly charged ions.

In our case for multiply-charged ion beams

$$E^i_{is} = \frac{N_i}{N_o} ,$$

where E^i_{is} is the efficiency of consuming a working substance in the production of ions in the i-th charged state from the ion source; N_o is the number of the atoms of the working substance, fed into the discharge per unit time; N_i is the number of ions with the charge i in the beam.

It is clear that E^i_{is} characterizes the ion source type and also the sort and the charge of the ions produced. But of practical importance for a physical experiment is also the total efficiency of consuming a working substance ($E^i_t = E^i_{ac} \frac{N_i}{N_o}$) where E^i_{ac} is the efficiency of ion acceleration and beam transport.

Conclusion

The investigations and the experience of using PIG and ECR ion sources at cyclotrons show that the problems of the effective production and acceleration of ion beams in a wide mass range can be successfully solved.

At the present time the efficiency of consuming a solid working substance is somewhat higher in PIG ion source than in an ECR ion source. It depends mainly on the technology of working substance feeding into the discharge chamber. But the ECR discharge has a higher efficiency of consuming gases for the production of highly charged ions.

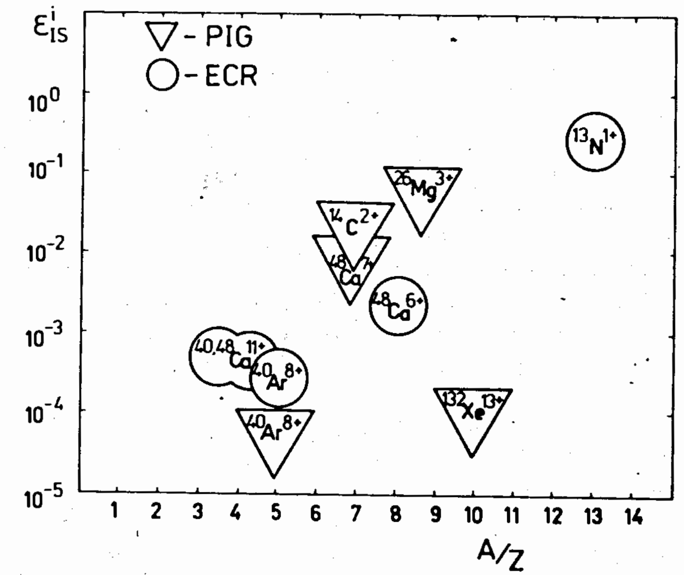

Fig. 1. Comparison of the efficiencies of consuming some working substances in PIG and ECR ion sources.

Table 3

Comparison of the efficiencies of consuming some working substances in PIG and ECR ion sources

Ion source	Ion	$\frac{m}{t}$, mg x h^{-1}	Q, cm^3 x min^{-1}	E_{is}	E_t
PIG	$^{14}C^{2+}$	-	0.03	$1.5x10^{-2}$	$1.5x10^{-4}$
	$^{26}Mg^{3+}$	4.4	-	$5x10^{-2}$	$1.2x10^{-3}$
	$^{40}Ar^{8+}$	-	0.6	$5.5x10^{-5}$	$3.3x10^{-7}$
	$^{48}Ca^{7+}$	4.0	-	$1x10^{-2}$	$1.2x10^{-4}$
	$^{132}Xe^{13+}$	-	0.4	$1x10^{-4}$	-
ECR	$^{13}N^{1+}$			$2.5x10^{-1}$	-
	$^{40}Ar^{8+}$	-	0.6	$3x10^{-4}$	-
	$^{40}Ca^{11+}$	2.1	-	$6x10^{-4}$	-
	$^{48}Ca^{11+}$	0.15	-	$6x10^{-4}$	$2.5x10^{-5}$
	$^{48}Ca^{6+}$	1.8	-	$1.6x10^{-3}$	$1.3x10^{-5}$

References

1. G.N.Flerov et al. Nucl. Phys. 1976, A267, p.359.
2. A.A.Efremov et al. In: IX All-Union Conference on Charged Particle Accelerators, JINR, Dubna, 1985, v.1, pp. 87-91.
3. C.M.Lyneis. In: Proc. Intern. Conf. on Cyclotrons and Their Applications. October 13-17, Tokyo, 1986,pp.707-712.
4. L.Bex et al. In: Proc. Intern. Conf. on ECR Ion Sources and Their Applications. November 16-18, East Lansing, 1987,pp.73-85.
5. D.Darquennes et al. In: Proc. Intern. Conf. on ECR Ion Sources and Their Applications. November 16-18, East Lansing, 1987, p. 491.
6. B.N.Gikal et al. Preprint JINR, 9-83-311, Dubna, 1983.
7. Yu.P.Tretyakov et al. In: VII All-Union Conference on Charged Particle Accelerators, JINR, Dubna, 1981, v.1, pp. 81-84.
8. S.L.Bogomolov et al. In: VIII All-Union Conference on Charged Particle Accelerators, JINR, Dubna, 1983, v.1, pp. 112-115.
9. V.B.Kutner et al. Preprint JINR, P7-85-362, Dubna, 1985.
10. T.S.Green. Nucl. Instr. and Meth., 1974, 115, p.615.

Received by Publishing Department
on June 29, 1989.