GANIL

CERN LIBRARIES, GENEVA

ICIS'97 - 7th International Conference on Ion Sources - Taormina, Italy, September 7-13, 1997
to be published in proceedings in Review of Scientific Instruments. Copyright by the American Institute of Physics.

Production of metallic ions with an ECRIS at GANIL

L. Bex, J. L. Flambard, M. Dupuis, P. Leherissier and J. P. Rataud
GANIL, Grand Accélérateur National d'Ions Lourds, P.O. Box 5027, 14076 Caen Cedex 5, France

GANIL A 97 01

Production of metallic ions with an ECRIS at GANIL

L. Bex, J. L. Flambard, M. Dupuis, P. Leherissier and J. P. Rataud
GANIL, Grand Accélérateur National d'Ions Lourds, P.O. Box 5027, 14076 Caen Cedex 5, France

A summary of recent and future developments in metallic ion production with an ECRIS at GANIL is presented. Multicharged metallic ions are routinely produced with an ECRIS (ECR4 14 GHz) and accelerated for nuclear and atomic physics experiments. We present the various methods which have been used to generate these multicharged metallic ions. The accelerator requires stable beams for periods of weeks. The results obtained recently by direct ion plasma sputtering of Ni, Nb and U samples are remarkable and stable beams from these metals have been delivered continuously for weeks. A pulsed EXCIMER laser, injecting a beam axially through the extraction hole of the ECRIS, has been tested for ablation on a rotating uranium target for uranium beam production. The MIVOC technique using volatile compounds has been also tested with ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$) to produce multicharged Fe ions. We plan to install a third high voltage platform using an ECRIS totally built with permanent magnets.

I. INTRODUCTION

The mass range of elements accelerated by the heavy ion accelerator GANIL extends from carbon to uranium. Many of these elements are usually available in the solid state and must be evaporated. Ion beam species obtained from the source are given in Table I. The techniques currently used at GANIL are : evaporation in an electrically heated oven, sputtering by ions extracted from the plasma and plasma heating by inserting into it a rod of pure metal or oxide. The laser ablation technique has been tested for U beams production. In addition the MIVOC (Metal Ions from Volatile Compounds) technique has been tested for Fe beam production using ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$).

GANIL is equipped with two compact injector cyclotrons CO1 and CO2 working alternately. CO1 receives the beam via an axial injection line and an ECR source (ECR4 14 GHz)¹ installed on a high voltage platform (100 kV). CO2 has axial injection as well with the same source on a 25 kV platform. Due to the high voltage platform difference the beam transmission through CO1 is 60 % and through CO2 only 25 %. We plan to install a new 100 kV platform, in parallel with the old one, injecting into CO1 and equipped with a source based on permanent magnets (SuperNanogan II). Thus the second injector may be used for atomic physics experiments. By using higher frequencies (18 GHz) and beam analysis at high voltage on the new platform we also hope to increase the extracted beam current.

II. COMPARISON OF EVAPORATION TECHNIQUES

Usually for the operation of the accelerator the beam delivered by the source must be maintained stable ($\pm 5\%$) over a one or two week period without interruption. The method of evaporation depends on the temperature necessary to obtain a vapour pressure of 10^{-2} mbar of the metal.

A. Oven technique

For temperatures below 1550 °C we use an oven (see Fig. 1). This technique presents the following advantages:

- (i) The consumption is low (from 0,2 to 1,0 mg/h) and small quantities of rare, expensive isotopes may be used.
- (ii) The evaporation is independent of the plasma characteristics, thus the source tuning is relatively straight forward.
- (iii) Oxides can be used and are often preferred to pure metals because they sublime before melting and for some at lower temperatures (MoO_3).

FIG. 1. High temperature oven.

B. Ion sputtering

This technique consists of placing a negatively biased metallic sample close to the ECR plasma as shown in Fig. 2. Positive ions from the plasma are accelerated toward the sample and after striking it atoms are evaporated into the plasma and ionised. The holder is water-cooled to prevent the copper part from melting.

This method has been applied successfully to Ni, Nb, and U. The characteristics of the uranium sample are given in Table II. The stability of the plasma is increased by using neon instead of oxygen as the support gas in the source as it is not pumped by the getter effect of the pulverised metal on the wall of the source chamber.

TABLE I. Metallic ions accelerated at GANIL.

Note that the source ion current is optimised for long-term stability but not for maximum intensity. The charge state is not always the most favourable because it depends on the parameters of the accelerator.

Ion	Evaporation technique (M) metal (O) oxide	Evaporation temperature at 10^{-2} mbar (°C)	Source Ion current (eμA)	Extraction voltage (kV)
$^{24}\text{Mg}^{7+}$	oven (M)	425	10	19
$^{28}\text{Si}^{6+}$	SiH_4 (gas)		23	19
$^{36}\text{S}^{6+}$	SF_6 (gas)		13	21
$^{40}\text{Ca}^{9+}$	oven (M)	600	10	25
$^{48}\text{Ca}^{8+}$	oven(CaO+Al)	2070 (CaO)	6	22
$^{50}\text{Cr}^{9+}$	oven (M)	1380	3	44
$^{52}\text{Cr}^{13+}$	oven (M)	1380	4	80
$^{58}\text{Ni}^{10+}$	oven (O)	1550 (NiO)	5	21
$^{58}\text{Ni}^{10+}$	sputtering (M)	1530	1,2	80
$^{64}\text{Zn}^{13+}$	oven (M)	340	6	21
$^{65}\text{Cu}^{13+}$	oven (M)	1240	3	84
$^{92}\text{Mo}^{16+}$	oven (O)	590 (MoO_3)	2	21
$^{93}\text{Nb}^{16+}$	sputtering (M)	2700	1,4	20
$^{93}\text{Nb}^{16+}$	rod insert (M)	2700	3	82
$^{106}\text{Cd}^{21+}$	oven (O)	770 (CdO)	4	20
$^{107}\text{Ag}^{19+}$	oven (M)	1020	3,5	18
$^{112}\text{Sn}^{22+}$	oven (M)	1220	3	84
$^{116}\text{Sn}^{16+}$	oven (O)	570 (SnO_2)	2	12
$^{125}\text{Te}^{20+}$	oven (M)	365	3	16
$^{154}\text{Sm}^{20+}$	rod insert (O)	1950 (Sm_2O_3)	3,5	66
$^{155}\text{Gd}^{19+}$	rod insert (O)	2046 (Gd_2O_3)	3,5	17
$^{181}\text{Ta}^{24+}$	rod insert (M)	3040	3	82
$^{208}\text{Pb}^{25+}$	oven (M)	718	3	65
$^{238}\text{U}^{24+}$	sputtering (M)	2100	1,8	66
$^{238}\text{U}^{28+}$	sputtering (M)	2100	0,9	81

The advantages of this technique are :

- (i) The beam is very stable for long periods and the exact position of the sample is not critical.
- (ii) Refractory metals can be evaporated and ionised.

The drawbacks are:

- (i) The yield is about 50% that of the other methods, most probably because the sputtering current drained by the sample is nearly the same as the total current (~1 mA) extracted from the source hole.
- (ii) The consumption of material is high (from 4 to 8 mg/h) and thus this technique can not be applied to rare, expensive isotopes.

TABLE II. Uranium sample characteristics.

length :	7 mm
diameter :	5 mm
weight :	2.7 g
percentage of ^{235}U :	0.2 %
consumption rate:	7.5 mg/h
distance from the plasma boundary:	15 mm
sample bias voltage :	-1800 V
sputtering current :	1 mA

C. Plasma heating

A rod of metal or oxide is introduced into the plasma where energetic plasma electrons vaporise the sample. To compensate for the evaporation of the tip, the sample must be continuously moved into the plasma. This technique

FIG. 2. Experimental set-up for metal sputtering in an ECRIS.

does not provide stable beams for long periods and as a result we are tending to replace it by the sputtering method.

III. NEW EVAPORATION TECHNIQUES TESTED

A. Laser ablation

A new technique using a pulsed EXCIMER laser (UV radiation) for evaporation of solid material into the source plasma was tested in our laboratory² in April 1995. A similar test has been performed at Argonne National Laboratory³ using a pulsed Nd:YAG laser beam (IR radiation). We used a KrF EXCIMER laser with the characteristics listed in Table III. The laser beam was injected through the extraction hole of the ECRIS to induce the ablation of a rotating uranium target (see Fig. 3). The particles ejected from the solid surface of the target are ionised in the plasma of the source which is fed with oxygen support gas. A 3 eμA average beam of $^{238}\text{U}^{25+}$ was obtained with a solid material consumption of approximately 1 mg/h. A laser pulse of ~30 ns duration generates a plume of emitted particles of ~200 μs duration which is transformed in the plasma into a beam pulse of ~20 ms duration.

The uranium sample was approximately 30 mm outside of the ECR plasma and placed on the axis of the source. The ablation was performed with a fluence of 0,6 to 0,8 J/cm² on the target. To avoid crater formation the sample was rotated at 2 Hz. The sample consisted of a cylinder (diameter : 8 mm ; weight : 6 g) inserted in a stainless steel holder. The focusing lens produced a laser spot with dimensions of 1 by 4 mm on the sample.

These preliminary results demonstrate that the laser ablation technique can be used in an ECRIS to produce beams from conductive and non conductive solid materials. This technique has not been adopted yet in our laboratory due to the high cost of the laser (\$100 000) and because its long-term stability is as yet unknown.

TABLE III. KrF EXCIMER laser characteristics.

emission wavelength :	248 nm
pulse width :	30 ns (FWHM)
maximum pulse energy :	250 mJ
maximum repetition rate:	200 Hz
maximum beam power :	30 W

FIG. 3. Experimental set-up used in the laser ablation tests.

B. MIVOC technique

The MIVOC technique which has been developed in Finland⁴ has been tested recently at GANIL with ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$).

FIG. 4. Charge state distribution of a Fe beam obtained by the MIVOC technique.

This technique can provide high currents of metal ions as shown in Fig. 4. It can be applied to other metals and probably to enriched isotopes, however it seems difficult to optimise the charge state distribution with a support gas because of the presence of a large number of C and H ions. The carbon probably contaminates the source and reduces the ion currents progressively. In addition some organo-metallic compounds are highly toxic and must be manipulated with safety precautions.

IV. THE NEW PLATFORM PROJECT

As noted earlier we plan to build a new platform injecting the beam into the injector cyclotron CO1 (Fig. 5).

FIG. 5. Schematic view of the two injector cyclotrons and their platforms.

The maximum potential needed is only 100 kV. By using a source built entirely from permanent magnets the size of the platform (Fig. 6) can be reduced to an area of 8.6 m² (3.3 by 2.6 m). The electric power required on the platform by the dipole, the vacuum pumps and the power supplies will not exceed 8 kW and will be produced by a motor-shaft-generator transmission unit.

The source, SuperNanogan II⁵, will be built with 160 kg FeNdB permanent magnets giving a hexapole field on the wall of $B_r = 1.3$ T. The plasma chamber dimensions will be the same as those of ECR4 ($\phi_{\text{int}} = 6.4$ cm; $L = 20$ cm). The RF power of the source will be supplied by a 18 GHz power generator placed at the ground potential near the platform.

FIG. 6. Schematic drawing of the new 100 kV platform.

5. CONCLUSION

We have described five techniques for metallic ion production that have been tested at GANIL, three of which being currently used for the regular operations of the accelerator : evaporation in an oven, by sputtering and by simple insertion into the plasma. The laser ablation technique has not been adopted yet because of the cost. Fortunately it can be replaced by the simple sputtering technique in the case of refractory metals. Tests will continue with the MIVOC technique to produce high intensity metallic ion beams. A project for a new platform equipped with an ECRIS composed of permanent magnets and working at 18 GHz has also been described.

¹P. Sortais et al., Proc. 3rd Int. Conf. on Ion Sources, Berkeley, USA, Rev.Sci. Instr. 61 (1), (1990) 288.

²L. Bex et al., Nucl. Instr. and Meth.in Phys. Res. A365 (1995) 564-567.

³R. Harkewicz et al., Proc. 12th Int. Workshop on ECRIS, Riken, April 25-27, 1995, Report INS-J-182 (1995) p. 19.

⁴J. Ärje et al., Proc. 12th Int. Workshop on ECRIS, Riken, April 25-27, 1995, Report INS-J-182 (1995) p. 136.

⁵P. Sortais, Private communication.