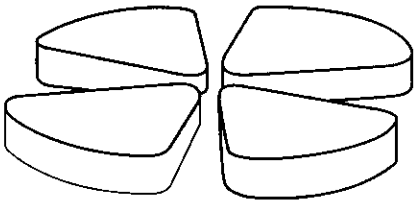
GANIL



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In the recent years, progress concerning the production of high intensity of metallic ion beams (^{58}Ni, ^{48}Ca, ^{76}Ge) at Ganil have been performed.
The MIVOC method has been successfully used to produce a high intensity nickel beam with the ECR4 ion source : 20 eμA of $^{58}Ni^{11+}$ at 24 kV extraction voltage. This beam has been maintained for 8 days and accelerated up to 74.5 Mev/u by our cyclotrons with a mean intensity of 0.13 pμA on target. This high intensity, required for experiment, led to the discovery of the doubly magic ^{48}Ni isotope.
The oven method has been first tested with natural metallic calcium on the ECR4 ion source, then used to produce a high power beam (740 W on target i.e. 0.13 pμA accelerated up to 60 Mev/u) of ^{48}Ca still keeping a low consumption (0.09 mg/h).
A germanium beam is now under development, using the oven method with germanium oxide.
The ionization efficiencies have been measured and compared

INTRODUCTION

Last years the GANIL heavy ions accelerator was equipped with several devices for protection against thermal effects and activation with the aim of producing exotic beams. Now it is in a position to deliver high beam power on the target up to 2 kW at 95 MeV/u and then up to a maximum value of 6 kW instead of previously 400 W [1]. For gaseous elements up to Argon the ECR ion sources deliver enough intensity to reach these values. But for condensable materials developments are underway. They have been successfully performed for some ions, and beams of ^{58}Ni (800 W), ^{48}Ca (730 W), and ^{36}S (1 kW) have been already used by the experimenters. Nevertheless developments are carried on to increase efficiencies and intensities of these metallic ion beams and the next one will concern ^{76}Ge beam.

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MIVOC METHOD FOR NICKEL AND IRON

In our case the previous intensities given by oven method for nickel beams were about 5 eμA of $^{58}Ni^{11+}$. The low ionization efficiency,1%, and the bad reliability lead us to investigate another method. The MIVOC (Metallic Ions from VOlatile Compound) method [2] is based on the use of high vapor pressure metallic compounds at room temperature: as an example, nickelocene $Ni(C_5H_5)_2$ has a vapor pressure of 3.5 10^{-3} mbar at 20°C. It could be an alternative for such metals with low vapor pressure which require a high temperature (1500°C) not suitable for long term stability with the oven method. Furthermore the impressive results obtained with the 18 GHz ECRIS at Riken [3] directed our research towards this method. Usually under powder form, the compound is placed in an hermetic box called MIVOC chamber, and is connected to the source via a rough regulation valve. The experimental set-up is represented in Fig. 1. The chamber is axially positioned, about 60 cm from the ECR plasma, and a mechanical valve with a maximum conductance of about 1 l/s for air is used to adjust the input flow. A removable MIVOC chamber designed for safety handling allows to measure the consumption while staying under vacuum. A balance measuring up to 1 kg with a precision of 1 mg is used for that.

All the results have been obtained without mixing gas, with the 14.5 GHz ECR4 [4] or ECR4M [5] ion sources installed on a 25 kV platform. The first tests carried out with ferrocene $Fe(C_5H_5)_2$ having a lower toxicity than nickelocene. A few days only were needed to condition the source and find the correct opening of the manual valve. An intensity of 92 eμA for $^{56}Fe^{9+}$ at 19 kV extraction voltage has been produced [6]. We have observed that the negative voltage (-150 V) applied to the biased tube (see Fig. 1) is of major importance : by short-circuiting the biased tube and the plasma chamber, the intensity for each charge state is strongly lowered. Elsewhere at ISMRA Laboratory the synthesis of ferrocene from enriched metal ^{58}Fe for further experiments has been done with an efficiency of nearly 100% [7]. After canalized the output flow of vacuum pumps through filter, we initiated tests with natural nickelocene. As for iron, 50 eμA of $^{58}Ni^{11+}$ beam has been easily obtained [7]. During the first high intensity nickel beam for physics experiments, we were not able to reproduce these results. An abnormal amount of oxygen was present in the spectrum. However a mean intensity of 20 eμA of Ni^{11+} was produced for 8 days. This nickel beam was accelerated up to 75 MeV/u with a mean intensity of 0.13 pμA on target. It led to the discovery of the doubly magic ^{48}Ni isotope [8].

At the beginning of the year 2000, the source ECR4 was replaced by an ECR4M . This change was justified by a detachment of some permanent magnets of the hexapole. This hexapole was then replaced by a Halbach type one, mechanically stable, and with a stronger magnetic field. The axial magnetic field has also been reinforced with a new set of coils.

Before the second run with nickelocene, the powder was outgased off-line for a few hours. A residual gas analyzer allows to observe a significant decrease of water [7]. Without refilling the mivoc chamber, the source ran for two weeks with a maximum stable intensity of 40 eμA of $^{58}Ni^{11+}$ (Fig.2). This intensity allowed to reach 770 W of power beam on the target i.e. 0.18 pμA at 75 MeV/u. Instabilities in close correlation with a shut down of the high voltage power supply were present during this run . These instabilities were not observed when running the source with pure argon at the same total intensity level (3 mA). A higher sensitivity in the extraction area with ECR4M, with such a compound, could explain this behavior. Investigations are planed in the near future. A nickelocene consumption of 3 mg/h has been measured i.e. 0.63 mg/h for the isotope ^{58}Ni. As the total number of ^{58}Ni ions measured on the Faraday cup was 21 pμA, for an average intensity of 24 eμA of $^{58}Ni^{11+}$, and taking into account the transport efficiency (39%) the ionization efficiency of the source for ^{58}Ni is around 18%.

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CALCIUM DEVELOPMENTS

The previous beam of ^{48}Ca accelerated at Ganil was produced from calcium oxide (enrichment 56%) mixed with aluminum powder in the axial oven [9]. The intensity delivered by the ECR ion source was around 7 eμA of $^{48}Ca^{10+}$ providing 50 W power beam on the target. As at JINR Dubna, we planned to improve the beam intensity, first using metallic calcium, then adding a hot tantalum sheet inside the plasma chamber [10] [11] .
The tests, with natural metallic calcium, have been run with the 14.5 GHz ECR 4 ion source at 76 kV extraction voltage, in its initial configuration : without tantalum sheet and without biased tube. We obtained rather easily a stable beam, 35 eμA of $^{40}Ca^{9+}$, with a consumption of 0.35 mg/h. Taking into account the beam transport efficiency from the ECR ion source to the Faraday cup (of about 0.7), the ionization efficiency for total calcium is 11%. An intensity of 80 μA was maintained for a few hours, (Fig.3) but the efficiency dropped down to 4%. Nevertheless, these first results allowed to operate with enriched (65%) isotope metal ^{48}Ca. In June 2001 a stable calcium beam was maintained for 3 weeks and accelerated up to 60 Mev/u. During this experiment the ECR 4 ion source was tuned several days at a maximum intensity of 22 eμA of $^{48}Ca^{10+}$ (Fig.4), i.e. 730 W on the target . After running six days, the average consumption of ^{48}Ca was 0.09 mg/h for an average $^{48}Ca^{10+}$ beam intensity of 17 eμA, giving an ionisation efficiency of 11%, the same as measured with natural calcium. Due to the various enrichment of samples (from 40 to 65%), and the different load weights (15 to 30 mg), we obtained various lifetime from 50 to 180 hours and quite different ionisation efficiencies ranging from 6 to 11%. These various isotopic compositions of ^{40}Ca, ^{44}Ca and ^{48}Ca allowed to observe an isotope effect in the CSD which shifted one charge state higher on ^{48}Ca compared to ^{40}Ca. After opening the source to recover the calcium deposited on the walls, we observed that the maximum deposition stands at the internal end of the coaxial tube, just in front of the oven located 9 mm inside this coaxial tube. That means that the ionization efficiency could be improved by moving the oven position, and also by using a tantalum sheet and a biased oven or coaxial tube. Preliminary tests with natural calcium show the shift of CSD from Ca^{10+} to Ca^{11+} when the coaxial tube is biased (-50 V).

GERMANIUM DEVELOPMENTS

Due to the chemical reactivity of Ge with refractory materials of the oven at high temperature (1400°C), we choose the oxide form, GeO2, requiring a lower oven temperature. Two runs with 75% enriched isotope ^{76}Ge have been performed. Neon then oxygen have been used as mixing gas. Oxygen gave the best results with a maximum stable beam $^{76}Ge^{13+}$ of 12 eμA. We measured an ionization efficiency around 10% for an average isotope consumption of 0.19 mg/h. Recent tests with natural Germanium oxide and Helium as mixing gas gave promising results providing a stable beam $^{74}Ge^{12+}$ of 11 eμA (37% enrichment) , and the final consumption of Germanium oxide was 0.6 mg/h .

IONIZATION EFFICIENCIES

Some standard ion beam species from the source to target are given in Table [I]. The source ion current for accelerator operation is optimized for long term stability according to the required current for users but not for maximum intensity. Total ionization efficiencies of metallic ions can be compared to Argon efficiency (50%). Note that for gaseous compounds ionization efficiency is reduced by the pumping in the injection part of the source. Without

injection pump, the ionization efficiency is around 80% for total argon [12]. The total ionization efficiency includes the transport efficiency, (around 70% with ECR4 running from 45 to 85 kV, and around 50% with ECR4M running from 15 to 25 KV). The enrichment value and the chemical formula are taken into account to calculate the isotope consumption. These values were obtained with Ar and SF6 gases, Nickelocene as mivoc compound, metallic Mg, Ca, and GeO2 with the oven method.
These results show that using carefully the method adapted to the element, big improvements concerning intensities and ionization efficiencies have been done. A good preparation of the MIVOC compound allows us to obtain reliability and high performances, half of the results reached at Riken. Developments of the oven method with a very rare isotope, as ^{48}Ca, leads to a high intensity beam with an ionization efficiency (11%) not so far than those measured with the MIVOC method (18%). Considering the higher intensities observed with natural calcium, then using tantalum sheets, biased coaxial tube and optimising the oven position it seems possible to improve again these results with ^{48}Ca.

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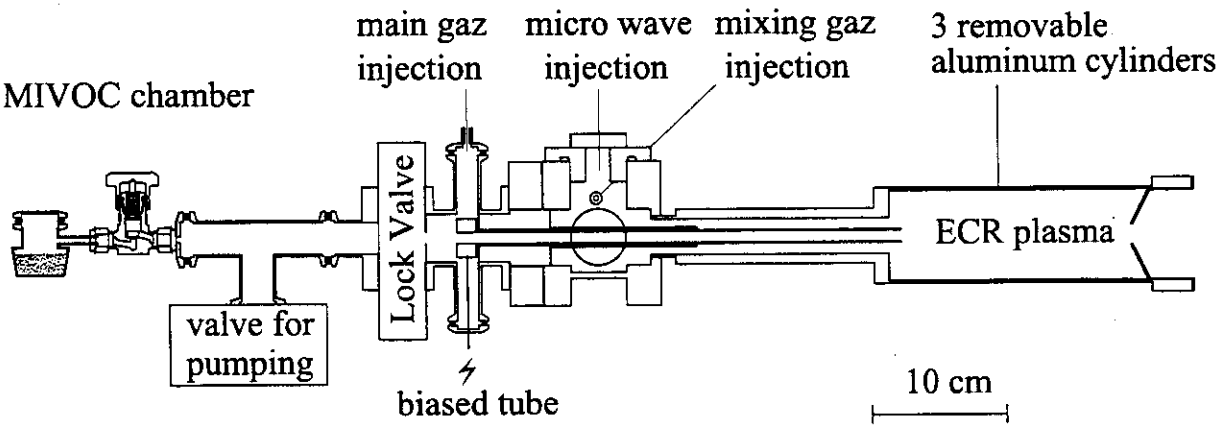

FIG 1. The MIVOC chamber installed with ECR 4M ion source.

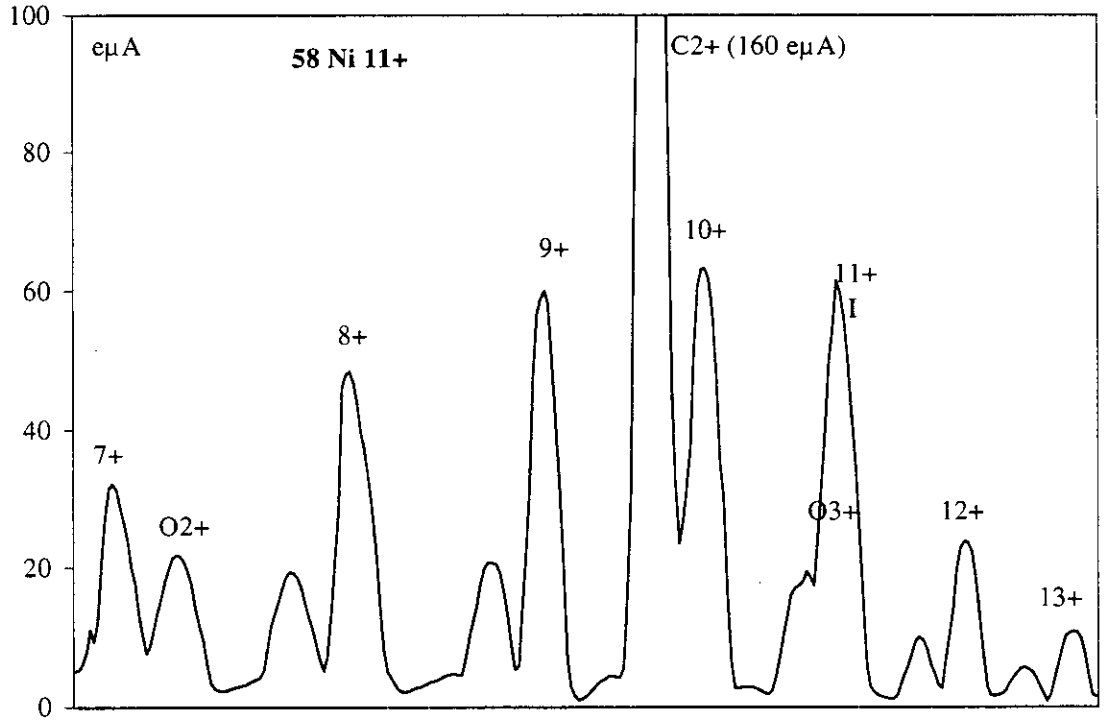

FIG.2 Nickelocene CSD spectrum optimised on 58 Ni 11+ at 45 eμA.
Extraction voltage 24 kV - extracred current 3 mA - RF power 230 W

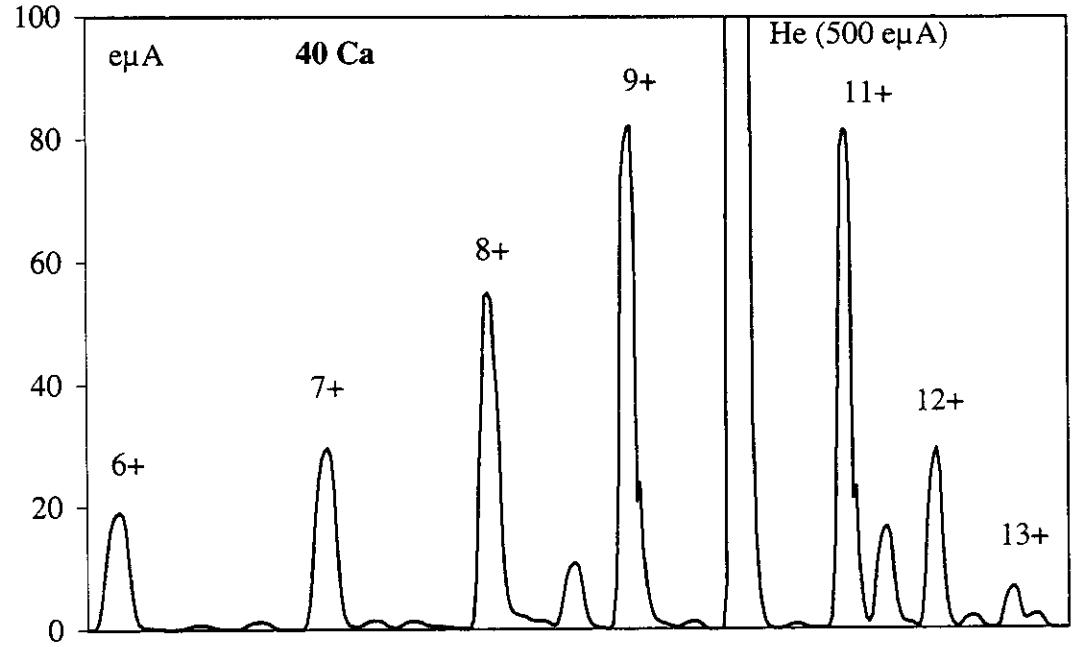

FIG. 3. Natural Calcium optimized on 40 Ca 9+ at 80 eμA
Extraction voltage 76 kV - extracted current 1,5 mA - RF power 330 W

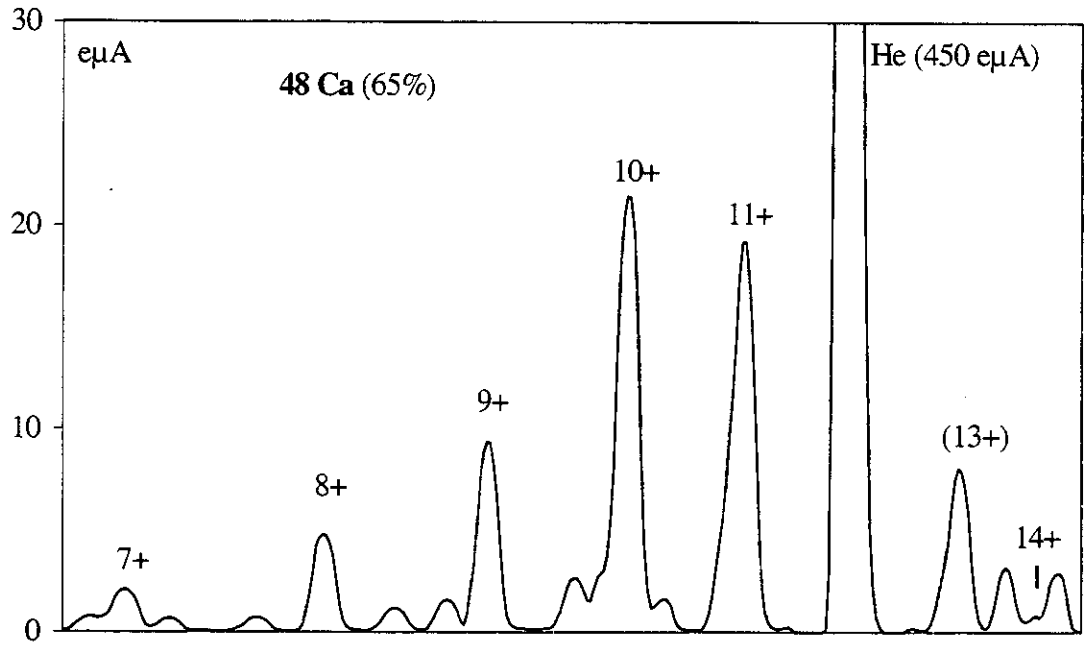

FIG 4. Calcium CSD optimized on 48 Ca 10+ at 22 eμA
Extraction Voltage 76 kV - extracted current 1,3 mA - RF power 210 W

ECR ion beam % isotope			isotope consumpt.	ionisation efficiency	On target		Beam Power	Energy
		eμA	mg/h		q	nAp	w	MeV/u
24 Mg 7+	79%	10	0,14	11%	12+	140	320	95
36 S 8+	63%	33	0,24	23%	16+	375	1000	77
36 Ar 10+	99%	50	0,48	50%	18+	580	2000	95
48 Ca 10+	65%	17	0,09	11%	19+	135	400	60
58 Ni 11+	68%	40	0,63	18%	26+	180	770	75
76 Ge 13+	75%	12,5	0,19	10%	30+	40	180	62

Table I. Recent results of Ganil standard beams
Total ionization efficiencies are corrected from transport efficiency