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## PRODUCTION OF METALLIC STABLE ION BEAMS FOR GANIL AND SPIRAL2\*

F. Lemagnen#, C. Barue, C. Canet, M. Dupuis, J.L. Flambard, L. Maunoury, B. Osmond, J. Piot, P. Jardin, R. Frigot, GANIL, Caen, France  
 C. Peaucelle, IPNL, Villeurbanne, France  
 P. Sole, T. Thuillier, T. Lamy, LPSC, Grenoble, France  
 B. Gall, Z. Asfari, H. Faure, M. Filliger, IPHC, Strasbourg, France

### Abstract

GANIL has been producing many stable beams for nearly 30 years. Constant progress has been made in terms of intensity, stability and reliability. The intensity for some stable metallic beams now exceeds or approaches the  $\mu\text{A}$  level at an energy up to 95 MeV/u: 1.14  $\mu\text{A}$  for  $^{36}\text{S}$  (65% enriched) at 77 MeV/u, 0.35  $\mu\text{A}$  for  $^{58}\text{Ni}$  (63%) at 74 MeV/u. The presentation highlights recent results obtained with  $^{50}\text{Ti}$  using the MIVOC (Metallic Ions from Volatile Compounds) methods on the ECR4 ion source. The Titanium beam was produced using the organo-metallic compound Titanocene :  $\text{Cp}^*\text{TiMe}_3$ . The synthesis of this metallocene compound has been successfully performed by the IPHC-Strasbourg from isotopically enriched  $^{50}\text{Ti}$  metal. Two tests have been done with the natural Titanocene ( $^{48}\text{Ti}$ ) to validate the new compound, and to qualify the intensity and beam stability. The good results obtained led us to program the Physics experiment in 2013, September and we have produced a very stable  $^{50}\text{Ti}^{10+}$  beam at an intensity of 20  $\mu\text{A}$  for 300 hours. The Spiral 2 facility, currently of installation, will provide gaseous and metallic stable ion beams. The ion source choice for the commissioning of the stable beams  $Q/A=1/3$  is the ECRIS PHOENIX V2. This ECRIS has been designed by LPSC Grenoble and several tests of stable metallic beams have been realized in this laboratory. The results for Nickel ( $^{58}\text{Ni}^{19+}$ ) and calcium ( $^{40}\text{Ca}^{16+}$ ) are given.

### PRODUCTION OF NEW METALLIC BEAM FOR GANIL: $^{50}\text{TI}$

#### Introduction

The study of a Titanium beam production started in 2011 with the ion source ECR4 by using the MIVOC method (Metal Ions from Volatile Compounds). This method was originally introduced at the University of Jyväskylä in Finland [1, 2, 3] and is routinely used at GANIL for the production of Ni and Fe beams, either using natural or isotopically enriched samples.

Thanks to the synthesis of the MIVOC compound Titanocene by B.GALL's team (IPHC-Strasbourg), an isotopically enriched  $^{50}\text{Ti}^{10+}$  beam was successfully delivered for physics experiment (E656-J.PIOT) in October 2013, during 15 days.

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# lemagnen@ganil.fr

#### Titanocene

The MIVOC method is based on the of the ECR ion source plasma feed by a controlled flow of organo-metallic compound. Such molecules are produced out of enriched material of desired element through dedicated chemistry. Nevertheless, only organo-metallic compounds with high enough vapour pressure can be used for MIVOC beams. It is for example the case for Fe, Ni and Mg where MIVOC method is widely used. Special care has to be taken to handle some of these compounds which are toxic.

With a melting point at 1660 °C for its metal form, titanium is typically a candidate to MIVOC method. Several years of developments were required to fully overcome the problematic of production and handling of this element. Several compounds were synthesized at IPHC Strasbourg and tested at University of Jyväskylä to successfully produce a MIVOC beam of titanium. Finally, first isotopically enriched MIVOC beam of titanium was obtained and accelerated in fall 2011 by the  $K = 130$  MeV cyclotron of the University of Jyväskylä. The Compound was produced with a quite high efficiency by a two-step chemistry starting with  $\text{TiCl}_4$  92.57 % enriched  $^{50}\text{Ti}$  element, then going to  $\text{C}_5(\text{CH}_3)_5\text{Ti}(\text{CH}_3)_3$  via  $\text{C}_5(\text{CH}_3)_5\text{TiCl}_3$ . A beam intensity of 19.4  $\mu\text{A}$  was extracted for titanium-50 at  $11^+$  charge state from the JYFL 14 GHz ECR2 ion source. This very stable beam – either on short and long time scale - was used for a three week experiment dedicated to the first prompt spectroscopy of a super-heavy element:  $^{256}\text{Rf}$  ( $Z=104$ ) [4].

Following this success, this compound was tested in GANIL Caen in collaboration with IPHC Strasbourg.

#### Transfer of the Synthesis in the MIVOC Chamber

Like the majority of organo-metallic compounds, the Titanocene is very air and moisture sensitive. The transfer of the synthesis in the MIVOC chamber is thus done under inert atmosphere (Argon). We used a portable glove bag (see Fig.1) for the sample manipulation. A special infra-red light has been used.



Figure 1: a portable glow bag for the sample manipulation.

### Analysis of the Synthesized Compound with the Gas Mass Analyzer

The purity is essential for the beam production with the MIVOC method. The measurement of the partial pressures with a gas mass analyzer allows us to evaluate the relative abundance of the impurities and their time evolution. It is thus a necessary step to qualify the synthesized samples.

We used a “transpector” gas mass analyzer from LEYBOLD to measure the partial pressures of the MIVOC compounds. The first measurement allows us to qualify the level of impurities without compound (valve closed). Once the compound injected into the analyzer chamber, several analyses are made to measure the partial pressures of the compound (see Fig.2). Usually we qualify the compound by determining the ratio of the highest partial pressure representing the metallocene (“XCp2”, “XCp” or “X”) over the highest partial pressure of the main impurity. The compound is considered operational after some hours of pumping when the ratio is higher than 5. For titanocene, we obtained  $Ti/H_2O = 6.2$  after 4 hours of pumping.

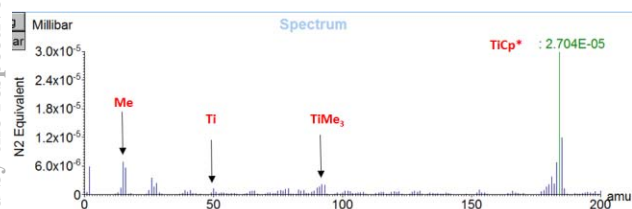


Figure 2: purified TiCp\*Me3 spectrum obtained with the gas mass analyzer.

### MIVOC Chamber Installed on ECR4 Ion Source

The injection of the compound into the source is controlled by a regulation valve. The fluctuating room temperature can change the flow injected in the ion source through the valve aperture. To get rid of this problem, we

have developed a system to control the temperature of the MIVOC chamber. The goal is to regulate the temperature between 20 and 25°C using a Peltier module. We had some problems during the run with a Peltier module: the ambient temperature was around 30°C and the power applied to the Peltier module was too high to obtain a temperature around 20°C (bad optimization of heat sink). To solve this default, a new prototype is being studied with a more powerful Peltier module (100w instead of 50w), a better thermal isolation of the MIVOC chamber and the improvement of the thermal conductivity between the Peltier module and the heat sink.

### Production of $^{50}Ti^{10+}$ with ECR4 Ion Source

After two tests (2011-2012) performed with natural material on ECR4 ion source leading to a 25 eμA very stable beam of  $^{48}Ti^{10+}$ , a beam of  $^{50}Ti^{10+}$  was programmed for the physics experiment.

The beam was delivered to the physics experiment for 480 hours. Two samples of Titanocene were used for the run.

The intensity was maintained at the exit of the source between 10 e.μA and 25 e.μA according to the physics requirements, what correspond to 2 and 4.5 e.μA on target at 4.82MeV/u (0.450 p.μA on the target).

### Source parameters optimized for $^{50}Ti^{10+} = 25e.μA$ :

RF power: 350W, biased tube: floating potential, no gas buffer, extraction: 25 kV / 3.2mA, coils current: 1010A / 1020A, injection pressure:  $1.3 \cdot 10^{-6}$  mbars, extraction pressure:  $3.3 \cdot 10^{-7}$  mbar.

The charge state distribution has been optimized on  $^{50}Ti^{9+}$  (see Fig.3).

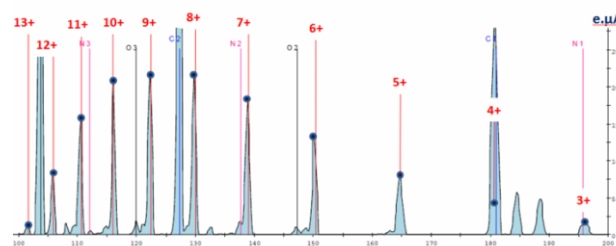


Figure 3: spectrum optimized.

### First sample:

Consumption: 2.5 mg/h (0.54mg/h of  $^{50}Ti$ ) ~ 190 hours  
Intensity:  $^{50}Ti^{10+} = 10$  to 20 e.μA with fluctuations (failure of PELTIER regulation)

### Second sample:

Consumption: 2 mg/h (0.43mg/h of  $^{50}Ti$ ) ~ 290 hours  
Intensity:  $^{50}Ti^{10+} = 15$  to 25 e.μA with a very good stability  
Total ionization efficiency: 8% (without transport correction)

**Conclusion**

The  $^{50}\text{Ti}^{10+}$  beam was successfully extracted and accelerated with GANIL cyclotron and it was transported on the target of the LISE apparatus for an experiment dedicated to the study of  $^{257}\text{Db}$ . The beam stability of the first sample was perturbed by a Peltier module dysfunction but, thanks to the change of Peltier module, the beam stability was better with the second sample. In 2015 a new experiment will be programmed. We will use a new Mivoc chamber with a better control of temperature.

**PRODUCTION OF METALLIC BEAMS FOR SPIRAL2**

**Introduction**

The PHOENIX V2 ion source will be used for the Spiral2 linear accelerator commissioning. This source has been designed and built up by LPSC Grenoble and will provide a beam of  $Q/A=1/3$  ions at  $60^*Q$  keV of maximum energy. Metal ion beam production (Nickel and Calcium) has been studied for 2 years with the PHOENIX V2 source installed on the SPIRAL2 low energy beam line [5] at LPSC Grenoble.

Production of  $^{58}\text{Ni}^{19+}$  Natural nickel sample ( $^{58}\text{Ni}:68\%$ ) and the Large Capacity Oven (LCO) [6] have been used for the tests. Helium buffer gas has been chosen for the first test. Stability and reproducibility have been observed and we obtained, after optimisation, a  $^{58}\text{Ni}^{19+}$  intensity of  $5\text{e.}\mu\text{A}$ . The charge state distribution was peaked on the  $^{58}\text{Ni}^{15+}$  ( $22\text{e.}\mu\text{A}$ ). In order to increase this intensity, we switched the buffer gas to oxygen. The  $^{58}\text{Ni}^{19+}$  intensity has been multiplied by 4 and the charge state distribution peaked on the  $^{58}\text{Ni}^{17+}$  (see Fig.4) [6]. However, we noted an important Getter effect leading to the decrease of the number of oxygen ions in the plasma. This chemical effect can affect the stability after a long time of run. A careful match of the oxygen flux with the oven evaporation rate was necessary to keep the ion beam stable. The consumption of  $0.4\text{mg/h}$  has been measured ( $0.25\text{mg/h}$  for  $^{58}\text{Ni}$ ) corresponding to a total ionization efficiency of  $6\%$  (without beam transport correction).

Source parameters optimized for  $^{58}\text{Ni}^{19+}=20\text{e.}\mu\text{A}$ :

RF power: 1.7 kW, oven position: 0 mm, oven electrical power: 71 W (oven temperature  $1450^{\circ}\text{C}$  off line), biased disk:  $-36\text{ V} / 0.5\text{ mA}$ , extraction:  $40\text{ kV} / 4.7\text{ mA}$ , coils current:  $1130\text{ A} / 1180\text{ A} / 1290\text{ A}$ , extraction:  $1.4 \cdot 10^{-8}\text{ mbar}$ .

**Production of  $^{40}\text{Ca}^{16+}$**

The optimization of  $^{40}\text{Ca}^{16+}$  beam was studied to check the possibility to produce  $^{48}\text{Ca}^{16+}$ . Natural calcium sample ( $^{40}\text{Ca}:97\%$ ) was evaporated by the LCO and tests were performed with several gas buffer. As a first test, we used Helium as buffer gas, since it is the one used at GANIL to

produce  $^{40}\text{Ca}^{9+}$ . The beam stability was correct but the charge state distribution was peaked on the  $^{40}\text{Ca}^{11+}$  ( $35\text{e.}\mu\text{A}$ ). No significant  $^{40}\text{Ca}^{16+}$  beam could be produced with the Helium buffer gas, so we decided to replace it by Oxygen.

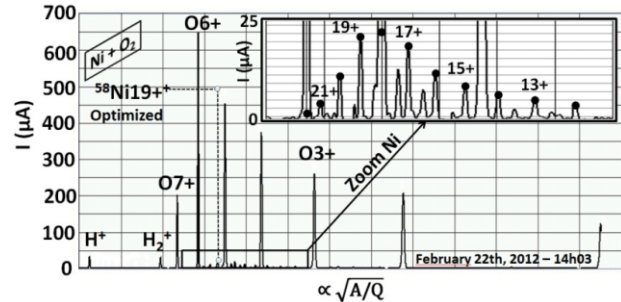


Figure 4: best spectrum optimized.

This time, it was impossible to obtain good beam stability because of strong getter effect. Injecting the buffer gas in the same injection tube as the LCO can increase the chemical effect.

The last test was carried out with nitrogen buffer gas. We observed a good beam stability for several hours and the charge state distribution was better than with helium buffer gas, with a spectrum peaked on the  $^{40}\text{Ca}^{13+}$  (fig.5) [7]. We obtained a  $^{40}\text{Ca}^{16+}$  beam stable with an intensity of  $16\text{e.}\mu\text{A}$ . One should note that the tuning was limited by the RF induced oven heating: the RF power could not be set above  $800\text{W}$ , which is not the optimum for high charge state production, expected above the kW level. A consumption of  $1\text{mg/h}$  was measured corresponding to a total ionization efficiency of  $4\%$  (without beam transport correction).

Source parameters optimized for  $^{40}\text{Ca}^{16+}=16\text{e.}\mu\text{A}$ :

RF power:  $800\text{W}$ , oven position:  $-15\text{ mm}$ , oven electrical power:  $0.4\text{ W}$  (oven temperature  $50^{\circ}\text{C}$  off line), biased disk:  $-9\text{ V} / 0.1\text{ mA}$ , extraction:  $30\text{ kV} / 1.2\text{ mA}$ , coils current:  $1170\text{ A} / 805\text{ A} / 1250\text{ A}$ , extraction:  $1.1 \cdot 10^{-7}\text{ mbar}$ .

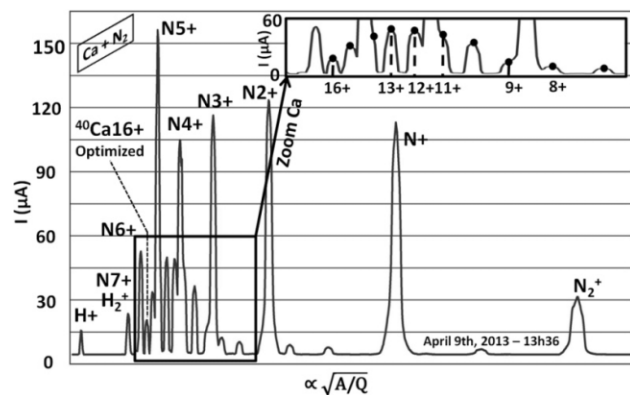


Figure 5: Optimized  $^{40}\text{Ca}^{16+}$  ( $16\text{ }\mu\text{A}$ ) spectrum.

### Conclusion

Hopeful results were obtained in term of beam stability and intensity for the  $^{58}\text{Ni}^{19+}$ . However these results will have to be confirmed during the commissioning of Spiral2. Concerning the production of  $^{40}\text{Ca}^{16+}$ , it's difficult to optimize the parameters in order to obtain reliable beams. Indeed the Getter effect and the evaporation control of sample due to the RF power were the main difficulties. To increase the performances, a new design of phoenixV2 injection has been studied with a pumping system. The main evolutions are to improve the vacuum level in the injection area and to separate the buffer gas injection from the oven injection. Another possible evolution would be to use a dedicated low temperature oven requiring tens of W heating power to sustain the calcium evaporation rendering any RF induced heating negligible.

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