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GANIL ION SOURCES: OPTIMISATION FOR OPERATION

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Abstract

The GANIL (Grand Accélérateur National d'Ions Lourds) in Caen has been producing and accelerating stable and radioactive ion beams for nuclear physics, atomic physics, radiobiology and materials irradiation since 1982.

Long-term stability of the beam, which is a key parameter for accelerator operation and success of physics experiments is targeted. At the same time, improving stability will also reduce the need of on-call work for ion source experts.

Recently, studies and tests have been carried out to increase the intensity and/or stability of the metal ion beams by modifying the injection of the ion source on ECR4/4M. Depending on the configuration, the gain on intensity shall be up to a factor of 2 on the charge state required for acceleration, and stability has also been improved compared to previous one.

INTRODUCTION

GANIL laboratory is initially based on Cyclotron accelerators able to produce Carbone to Uranium ion beam with a maximum energy of 95MeV/u. To provide ion beams, two 14 GHz ECR4/4M ion sources [1, 2] are installed into the machine injectors. They provide around 4000 hours of total beam per year, of several type of ions (Fig. 1).

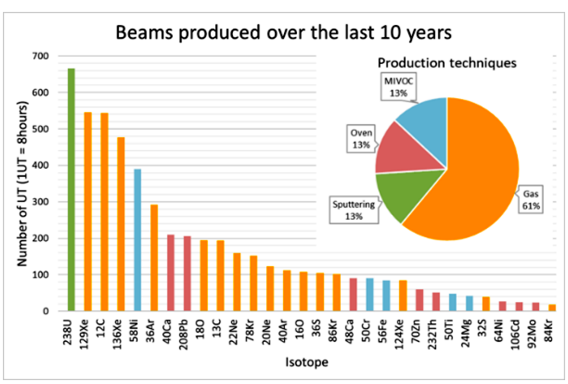

Figure 1: Beams produced by ECR4/4M over the last 10 years.

On the new SPIRAL2 accelerator (based superconducting LINAC), two injectors are installed: One dedicated to light element (2.45 GHz – H^+/D^+), and one dedicated to heavy ions (18 GHz – A/Q<3 - Phoenix V3). Main beams produced are currently proton and deuteron beams for Neutron for Science experimental hall, until the S^3 facility starts its experimental programme in 2026.

New experimental facilities will be set up in the coming years to offer more scientific possibilities for physicists. At the same time, new projects are being under construction or studied to deliver new attractive ion beams (Fig. 2).

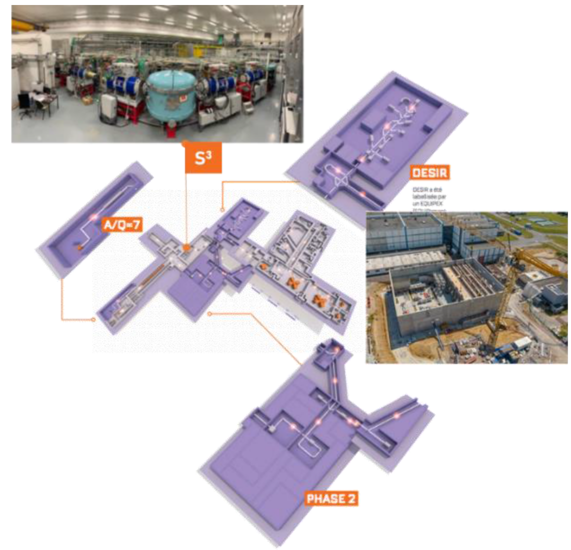

Figure 2: Layout of actual and future building at GANIL.

S^3

The Super Separator Spectrometer (S^3) [3] set up will start running in 2026 for the production and studies of super heavy elements. To create them, a high intense heavy ion beams (Q/A=1/3 => $^{14}Ca^{14+}$, $^{48}Ca^{16+}$, $^{58}Ni^{19+}$, 2 pµA) have to be provide by the heavy ion source injector on SPIRAL2 over a long period (3 weeks–1.5 month).

DESIR

DESIR [4] experimental hall, currently under construction, will use radioactive ion beams produced by S^3 and SPIRAL1 facility at 2027 horizon for experiments with low energy beams.

NEWGAIN (A/Q<7)

The NEWGAIN project [5] aims to install a new injector (Ion source + RFQ) for the SPIRAL2 accelerator with the goal of accelerating a beam characterized by A/Q<7.

A new 28 GHz superconducting ions source ASTERICS [6] is being studied to provide a 10 pµA of metallic beams up to ^{238}U. The new low-energy beamline and a RFQ are currently under construction and will start operating by 2028. The ion source will be assembled and commissioned at LPSC, Grenoble and hence moved to GANIL by 2030.

Future Upgrade for GANIL-SPIRAL2

Beyond 2030, future upgrade applied to GANIL-SPIRAL2 [7] is under evaluation: the design of a new radioactive ion beam (RIB) production facility that will be able to provide RIBs to DESIR for low-energy experiments or to adapt the beam to accelerate it to a range of 50–70 MeV/u before sending it to GANIL's existing experimental areas.

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CHALLENGES FOR FUTURE OPERATION AT GANIL-SPIRAL2

By 2030, GANIL aims to increase the beam time available on both machine, to over seven months per year. This represents a significant challenge, as it requires the simultaneous operation of multiple ion sources, each optimized for specific operations.

By 2026, S^3 will requiring new metallic ion beams optimised to deliver an intensity up to 2 pµA, initially with the A/Q<3 SPIRAL2 injector, and up to 10 pµA with the new Asterics 28 GHz SC ion source injector (A/Q<7).

Combined with these objectives, the aim of the cyclotron facility is to ensure that the facility can meet the demands of the nuclear physics community for the next 20 years. This requires continuous improvement in term of stability, intensity, and operational reliability. To achieve this objective, a project is underway to increase the reliability of the cyclotron accelerator complex, by changing or refurbishing the old power supplies, RF cavities, cooling system, etc.

CYCLOTRON ION SOURCES OPTIMISATION

Requirements for performances of ion sources on cyclotron accelerators are to provide beams with medium charge states of beam from Carbon to Uranium, with an intensity in the range of 1 µAe to a maximum of 50 µAe (maximum intensity usable by cyclotron). ECR4/4M ion sources are able to produce beams from gaseous and metallic elements by using several technique, like sputtering rod, oven and MIVOC. For the next 20 years, some studies are underway to evaluate the possibility to change ion sources to increase intensities available for physicist, especially for beams between Nickel to Uranium where ECR4/4M ion sources have some intensities limitation.

In the meantime, some studies was carried out on current ions sources to optimise the stability and improve intensities.

Stability

Cyclotron ion sources are located in the main cyclotrons building, where temperature variations of up to 10 °C can be observed depending on external conditions, leading to fluctuations in several parameters (extraction pressure, drain current, beam intensity). As a result, operators must regulary adjust parameters to stabilize the beam intensity. For example, in 2022 with $^{48}Ca^{10+}$ beam, 15 adjustments were necessary over two days to limit the intensity variation around 40 %. The initial source settings gradually degrade, which requiring sometimes a complete tuning by an expert. Analysis revealed that the UDV valves were the most sensitive to external conditions. To fix this, a temperature regulation at 40 °C was installed around the valves, immediately stabilizing the injected flux. Improvement was observed with a $^{129}Xe^{23+}$ beam, showing around 5 % stability over four days without adjustments. This was also noted with metallic beams with $^{238}U^{31+}$ beam. Online adjustments were reduced during 15 days operation: 45 in 2023 compare to 5 in 2024.

Diagnostic

On-line non interceptive diagnostic is one of the main requirement for monitoring ion sources, particularly when beam is delivered as part of physics experiments. Optical Emission Spectroscopy (OES) is a technique already used in other laboratories [8]. In our case, an optical fibre was installed directly behind a glass window in line with the injection source. This location allows us to be close to the plasma and effectively detect the photons emitted by plasma. Connected to the optical fibre, a visible light spectrometer (model FLAME from OceanOptics) measure intensities emitted on a range of wavelengths between 350 nm and 1000 nm.

To evaluate this technique for on-line diagnostic, a plasma of Argon + Helium was produced, with an intensity of 80 µAe of $^{40}Ar^{9+}$ measured on Faraday cup after the mass separator. A measurement of light emitted by the plasma was carried out and analysed to get an initial situation of the plasma parameters (Fig. 3).

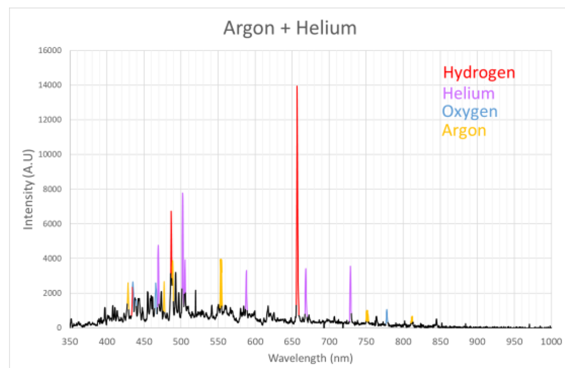

Figure 3: Measurement of light emitted by Argon + Helium plasma on ECR4M. Identification of wavelength: Hydrogen (H I= 656 nm), $^{40}Ar^{9+}$ (Ar X = 553 nm) and Helium (He I = 668 nm). *Data from the NIST website database.*

Ion source parameters was monitored along 2 days without any tuning modifications: intensity on FC, drain current, extraction pressure, building temperature (Fig. 4) and intensities of the three wavelength selected (Fig. 5).

Conclusions of these measurements are:

- Outgassing from the vacuum chamber due to rising building temperatures leads to hydrogen pollution in the plasma. This uncontrolled hydrogen altering the initial tuning and affecting the source delivered intensities. To improve beam stability, controlling this pollution is necessary.
- The OES used as diagnostic is able to give information about the quantity of elements present into the plasma. That mean it's possible to have an idea of intensities extracted by the source without interceptive measurements as show with Ar^{9+} in Fig. 5. This technique have to be used for metallic ion beam to estimate atom flux deliver by the oven along the time.

These measurement shown that it could be interesting to develop a specific diagnostic to help operators during experiments.

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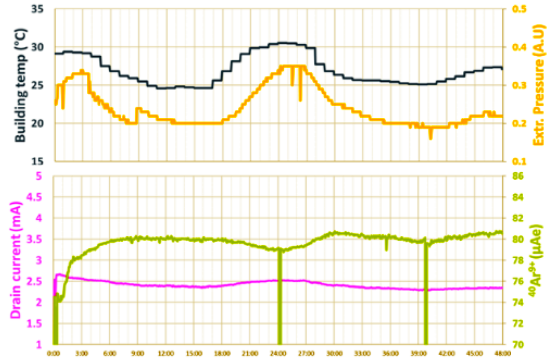

Figure 4: Evolution of ion source parameters and building temperature.

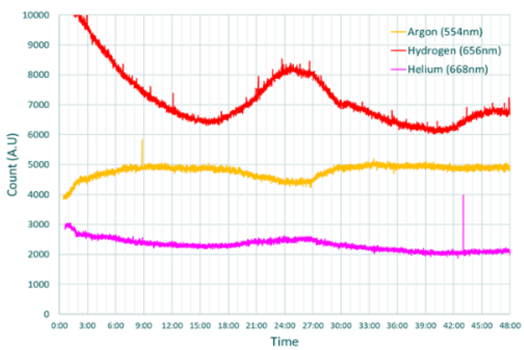

Figure 5: Evolution of light intensities of selected wavelengths.

Improvements of Metallic Ion Beams

Up to 2021, the standard ECR4/4M ion source configuration was used, especially at the injection side where oven, sputtering rods and MIVOC technic was designed to be inserted into the coaxial RF tube transition. This situation involve some limitations, especially considering the diameter of device have to be insert close to plasma chamber. Moreover, electrical configuration of the high voltage platform/cabinet did not allow to bias the oven.

Since 2021, tests have been carried out to adapt the source injection to better optimised devices. For example, we observed limitations when using the MIVOC technique concerning the amount of vapour that could be injected into the plasma chamber due to the low conductance between the sample and the plasma chamber. In 2022, the original coaxial tube was removed and replaced by a wider tube between the sample and the plasma chamber. The results show that we were able to increase the intensity of the $^{58}Ni^{11+}$, with better stability for more than 2 weeks without any technical problems.

Uranium Beam and High Temperature Oven The uranium beam has been the most used beam at GANIL over the last 10 years. Up until now, the sputtering method was used to produce this beam. Following the development of the resistive high-temperature oven [9] at GANIL, a test of uranium production from a UO_2 compound was carried out on the ECR4M source. The source injection was modified to accommodate this new oven, which has an external diameter of 20 mm. In this configuration, the oven acts as a coaxial tube for RF injection.

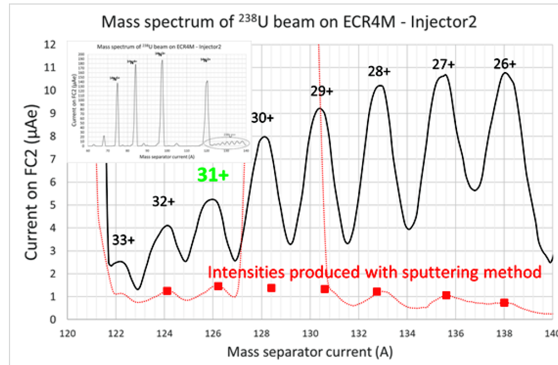

Figure 6: Charge state distribution of Uranium beam produce with HT Oven. Conditions: Oven 107 A (>1900 °C), N_2 support gas, HV: 20.6 kV, RF power: 400 W, no bias.

Results of this test shown:

- The resistive HT Oven is able to evaporate UO_2 into an high magnetic field configuration.
- Performances with oven are better than sputtering method (× 3.3 on 31^+, × 5 on 28^+), see Fig. 6.
- RF transmission is not affected by the size of oven.

The beam was tested for 3 days with an intensity of 3 µAe of $^{238}U^{31+}$.

Bias Oven Applied for Metallic Ion Beam Production Bias disc effect is a technique used to improve the extraction of beam, especially for high charge state beam [10]. To evaluate the potential improvement for metallic ion beams at GANIL, a test was carried out with Lead beam on injector 2-ECR4M. First of all, a standard configuration was used, without bias oven or coaxial tube. After optimisation to maximize 28^+ charge state, performances were similar to reference [11]. Secondly, the electrical configuration was changed to be able to bias the oven. An optimisation was done on 28^+ charge state. The results meet with conclusions of bias disc effect: The beam transport up to the first faraday cup increase by a factor 2 (average on all charge state), and the intensities extracted from the ion source increased for high charge states (Fig. 7).

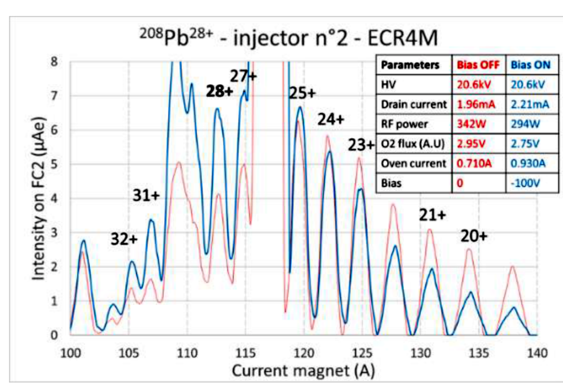

Figure 7: Charge states distribution comparison between bias oven and no bias oven.

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Another tests was performed with O, Ar, Xe gas and results are similar. Conclusion is that the used of bias oven can improve all metallic ion beam produce by oven technique by a factor of 2. In consequence, electrical configuration is under modification on both cyclotron injectors to get the possibility of biasing oven for the future beams.

SPIRAL2 HEAVY ION SOURCE

The A/Q<3 injector will be used to provide high intensity, high charge state metallic and gaseous beams to LINAC for long term operation (3 weeks to 1.5 month depending the physics experiments). To meet the requirement, a 18 GHz room temperature ion source was designed, and commissioning at LPSC up to 2019, called Phoenix V3. Intensities produced by the ion source are close to required intensities (i.e >10 pμAe for light gaseous beam (O, Ne, Ar) and between 1 and 2 pμAe for metallic one (Ca, Ni).

Reliability

After one year of operation and commissioning at GANIL (40 kV and 60 kV operation), technical problems have been identified to meet with long-term 60 kV operation. Investigations and modifications have been done between 2022 and 2023 to improve reliability of the injector:

- The injection plug was adapted to protect the bias discs insulators to reduce metallisation. At the same time, the hole for oven port has been increase to 25 mm.
- The extraction electrodes have been modified, in length and shape to protect insulator to metallisation.
- The coils located in iron yoke has been protected from internal insulator by stainless steel liner and a Kapton layer because of electric impact was observed.

Metallic Beams Optimisation

The ^{48}Ca beam is a beam requested for the S^3 scientific programme. Because of the rarity of this isotope, an effort must be made to maximise the efficiency of the ion source in order to reduce isotope consumption. One way to reduce this consumption is to use a hot liner installed in the plasma chamber, the aim of which is to re-evaporate the calcium atoms that have not interacted with the plasma.

This technique was tested with the Phoenix V3 ion source and a 0.1 mm Tantalum liner was inserted into the plasma chamber. After a period of outgassing, Tantalum pollution was observed on the mass spectra, and the experiment was then interrupted. Finally, a hole appeared in the liner, revealing a degradation of the radial magnetic field. Magnetic field measurements confirmed this degradation (Fig. 8).

The hexapole was dismantled from the ion source and investigations were carried out. Finally, a magnet was found broken (30° S near the main pole magnet).

All these modification were effective by spring 2024. Last results for He^{2+} an $^{40}Ar^{14+}$ indicated an improvement on beam intensities around 20 % ($^{40}Ar^{14+}$: 130 => 156 μAe; $^{4}He^{2+}$: 4.3 => 5 mA).

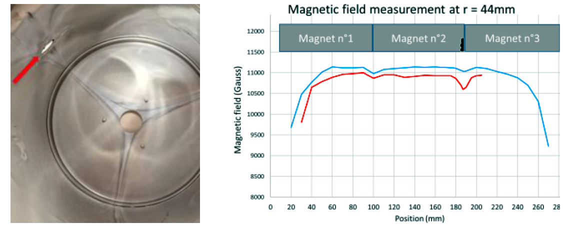

Figure 8: Hole on Tantalum liner (left), radial magnetic field measurement before (red) and after (bleu) repair.

CONCLUSION AND PERSPECTIVES

GANIL got ambitious objectives about technical development to increase beam time with new setup for physics experiments. On cyclotron, some ways are existing to improve the beam quality coming from ECR4/4M ion source meanwhile a potential new ion sources installation. These improvements have now to be used on-line after an electrical adaptation on HV platform.

On SPIRAL2, heavy ion source is now reliable and available to progress on beams development. A program is identified to reach 2 pμA for species like ^{48}Ca, ^{50}Cr, ^{50}Ti, by using new inductive/resistive high temperature oven, recycling technique, double frequency, OES.

REFERENCES

[1] P. Sortais *et al.*, “Ecris development at GANIL”, *Rev. Sci. Instrum.*, vol. 61, pp. 288–290, 1990. doi:10.1063/1.1141324

[2] R. Leroy *et al.*, “ECRIS optimisation for on line production”, in *Proc. 12th ECRIS Workshop*, Wako, Japan, 25-27 Apr 1995, Japan, vol. INS-J-182, p. 57. https://inis.iaea.org/collection/NCLCollectionStore/_Public/28/037/28037314.pdf

[3] A. Douart *et al.*, “The Super Separator Spectrometer (S^3) for the SPIRAL2 facility”, *J. Phys.: Conf. Ser.*, vol. 1643, p. 012032, 2020. doi:10.1088/1742-6596/1643/1/012032

[4] B. Blank, “The DESIR facility at SPIRAL2”, *Pramana-J. Phys.*, vol. 75, pp. 343-353, 2010. doi:10.1007/s12043-010-0121-9

[5] M. H. Moscatello *et al.*, “NEWGAIN project at GANIL-SPIRAL2: design of the new heavy ion injector for the superconducting linac”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 1765-1767. doi:10.18429/JACoW-IPAC2023-TUPA193

[6] T. Thuillier *et al.*, “ASTERICS, a new 28 GHz electron cyclotron resonance ion source for the SPIRAL2 accelerator”, *J. Phys.: Conf. Ser.*, vol. 2743, p. 012059, 2024. doi:10.1088/1742-6596/2743/1/012059

[7] H. Franberg Delahaye *et al.*, “Future upgrades for GANIL”, in *Proc. IPAC’24*, Nashville, TN, May 2024, pp. 1199-1201. doi:10.18429/JACoW-IPAC2024-TUPC79

[8] F. Maimone *et al.*, “Stable and intense Ca ion beam production with a microwave shielded oven and an optical spectrometer as diagnostic tool”, in *Proc. ECRIS’20*, East Lansing, MI, USA, Sep. 2020, pp. 50–53. doi:10.18429/JACoW-ECRIS2020-MOZZO03

ISBN: 978-3-95450-257-8 ISSN: 2222-5692 doi:10.18429/JACoW-ECRIS2024-MOB1

[9] O. Bajeat *et al.*, “Metal evaporation study using the GANIL high temperature oven for intense metal ion beams production”, *J. Phys.: Conf. Ser.*, vol. 2244, p. 012017, 2022. doi:10.1088/1742-6596/2244/1/012017

[10] L. Kenéz *et al.*, “Study of the biased-disc effect using Langmuir-probes inserted in the hot region of the electron cyclotron resonance ion source (ECRIS) plasma”, *Phys. Lett. A*, vol. 372, no. 16, pp. 2887-2892, 2008. doi:10.1016/j.physleta.2007.12.037

[11] C. Barue *et al.* “Status Report on Metallic Beam Production at GANIL/SPIRAL 2”, in *Proc. ECRIS2016*, Busan, Korea, Aug.-Sep. 2016, pp. 92–97. doi:10.18429/JACoW-ECRIS2016-WEPP05