

# STUDY OF ION SOURCES USING OPTICAL EMISSION SPECTROSCOPY FOR BEAM MONITORING

A. Ribet<sup>†</sup>, M. Dubois, L. Gouleuf, F. Lemagnen, V. Metayer, B. Osmond  
Grand Accélérateur National d'Ions Lourds, Caen, France

## Abstract

Non-interceptive online diagnostics are essential for monitoring ion sources, particularly during physics experiments. Optical Emission Spectroscopy (OES), already used in other laboratories, has been tested at GANIL. The light emitted by the plasma is captured by a CCD camera placed behind a glass window aligned with the ion source and by an optical fiber connected to an optical spectrometer (350-1000 nm). Initial tests were carried out with Ar + He plasma, with an intensity of 80  $\mu$ Ae of  $^{40}\text{Ar}^{9+}$  measured after the mass separator. Additional studies were performed online in 2025 with a  $^{70}\text{Zn}^{14+}$  metal beam. Optical measurements made it possible to track changes in the light intensity of the identified wavelengths over time. The use of this technique also provided access to new information (effect of temperature variation, presence of pollution within the plasma, evaluation of the metal ion population) and helped to better identify the needs for optimizing the source settings. These various measures demonstrate the value of developing a dedicated diagnostic tool to continuously monitor beam stability and assist operators during experiments. To this end, initial work has been carried out on automating the analysis of measured optical spectra (definition of baselines, detection and identification of peaks, etc.). This represents the first step towards ultimately achieving complete automation of source adjustments.

## MANUSCRIPTS

## Introduction

Optical Emission Spectroscopy (OES) is used to monitor the source stability during operation. It is a simple *in situ* diagnostic technique that does not perturb plasma properties. It enables the estimation of key plasma parameters, such as instabilities, the quantity of elements injected into the source, the presence of impurities, and the oven temperature. This technique has been tested and employed in several laboratories, including GSI Helmholtz Centre for Heavy Ion Research, over the past few years [1, 2]. In 2025, initial tests were carried out at GANIL [3].

The diagnostic setup is aligned with the source, downstream of the first mass-separation dipole. Light emitted by the source (from both the plasma and the oven) is collected and focused using a telescope. The signal is then split by a beam splitter, directing 50% of the light to a

CCD camera and the remaining 50% into an optical fibre via a collimator. The fibre is connected to the optical spectrometer (Ocean Optics Flame model) for measuring spectral line intensities. The detection system was calibrated over the wavelength range 350–1000 nm.

## Results

The OceanView software (basic software supplied with the device) enables the observation of spectral line intensities over the selected wavelength range and allows monitoring of peak intensity evolution as a function of time. A typical emission spectrum for a  $^{70}\text{Zn}^{14+}$  beam using  $\text{N}_2$  as support gas is shown in Fig. 1. The measurement was performed with a High Frequency (HF) power and an oven power of 152 W and 0.37 W respectively (operating conditions).

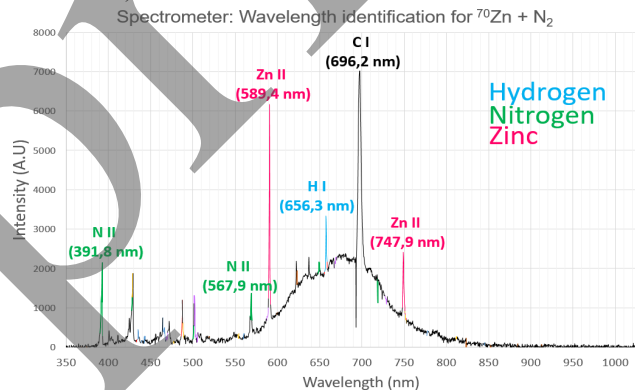


Figure 1: Emission spectra of a  $^{70}\text{Zn}^{14+}$  beam using  $\text{N}_2$  as support gas ( $P_{\text{HF}} = 152$  W,  $P_{\text{oven}} = 0.37$  W).

The analysis of selected spectral features [4] reveals the presence of two nitrogen emission lines (N II at 391.8 and 567.9 nm), two zinc lines (Zn II at 589.4 and 747.9 nm), one hydrogen line (H I at 656.3 nm), and one carbon line (C I at 696.2 nm). The detection of carbon and hydrogen species in the plasma is likely attributable to the degradation of source and oven components under operating conditions. An overall increase in emission intensity is observed across the 550–850 nm spectral range, suggesting a broadband contribution correlated with the thermal state of the source, and in particular the oven temperature, despite the low power applied. In addition, monitoring the Zn emission lines provides a reliable indicator for tracking real-time variations in the beam current delivered by the source.

Figure 2 displays the temporal evolution over 12 days of operation of key source parameters, including the zinc beam current and injection pressure, together with the intensities of selected emission lines: Zn II at 589.4 nm and N II at 391.8 nm. In addition, CCD camera images acquired

<sup>†</sup>alexis.ribet@ganil.fr



chamber outgassing and support gas injection, respectively. Periodic fluctuations similar to those mentioned previously are also observed. Such monitoring enables real-time identification of whether variations in the ion beam current measured at the FC originate from fluctuations in the support gas or from the oven. Furthermore,  $I_{HT-S}$  constitutes a key parameter for assessing ion source stability. Maintaining a constant  $I_{HT-S}$  value contributes to sustaining the plasma and plays an important role in its stabilization.

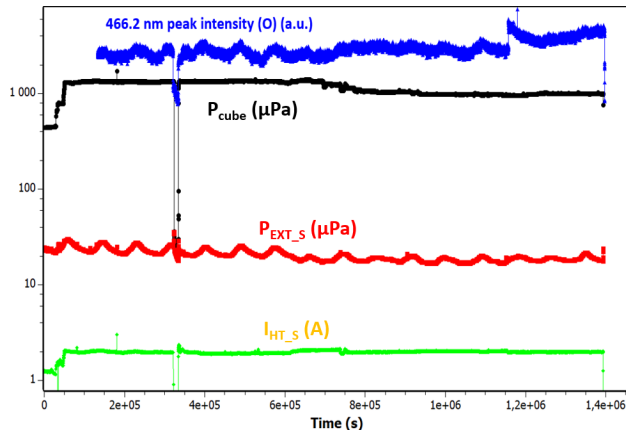


Figure 5: Temporal evolution of the oxygen peak intensity (O II at 466.2 nm) compared with variations in cube pressure ( $P_{cube}$ ), extraction source pressure ( $P_{EXT-S}$ ), and ion source current ( $I_{HT-S}$ ).

It is noteworthy that, even in the absence of a directly observable tungsten emission line, monitoring alternative parameters enables effective optimization and control of the source.

## CONCLUSION

Optical Emission Spectroscopy (OES) has been successfully implemented as a non-interceptive diagnostic tool for monitoring ion source behavior during operation at GANIL. The results demonstrate that OES provides reliable, real-time information on plasma conditions, enabling the identification of key parameters such as impurities, injected species, and thermal effects related to the oven. A strong correlation between optical signals and ion source parameters has been established, highlighting the capability of OES to track variations in beam current, pressure, and plasma stability. In particular, the monitoring of specific emission lines, as well as integrated spectral intensity, allows the detection of fluctuations linked to environmental conditions, operational settings, and transient instabilities in the source. Even in cases where the element of interest (e.g., tungsten) is not directly observable, indirect indicators derived from the spectra provide effective means for source optimization and control. Furthermore, the implementation of advanced acquisition and analysis tools enables real-time diagnostics. These developments significantly enhance the ability to support operators during experiments and to improve the stability and reproducibility of ion beams. Overall, OES proves to be a powerful and versatile

diagnostic technique for routine operation, contributing to more efficient optimization of ion source settings and improved beam stability. Future work will focus on the deployment of additional OES systems, in particular on the SPIRAL2 heavy-ion source, and on the extension of diagnostics to metallic ion beams of interest for the S<sup>3</sup> program (e.g., <sup>48</sup>Ca, <sup>50</sup>Ti, <sup>54</sup>Cr). Continued efforts toward automation of spectral analysis represent a key step toward fully automated source tuning.

## REFERENCES

- [1] F. Maimone *et al.*, “Stable and Intense <sup>48</sup>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-MOZZ003](https://doi.org/10.18429/JACoW-ECRIS2020-MOZZ003)
- [2] F. Maimone, Andreev, A., Galonska, M., Hollinger, R., Lang, R., Mäder, J., & Patchakui, P. T. “Research and development activities to increase the performance of the CAPRICE ECRIS at GSI”. *J. Phys.: Conf. Ser.*, vol. 2743, No. 1, p. 012048, 2024.  
[doi:10.1088/1742-6596/2743/1/012048](https://doi.org/10.1088/1742-6596/2743/1/012048)
- [3] M. Dubois *et al.*, “GANIL ion sources: optimisation for operation”. in *Proc. 26th International Workshop on ECR Ion Sources*, Darmstadt, Germany, Sep 2024, pp. 5-9.  
[doi:10.18429/JACoW-ECRIS2024-MOB1](https://doi.org/10.18429/JACoW-ECRIS2024-MOB1)
- [4] Y. Ralchenko *et al.*, NIST atomic spectra database. *NIST Atomic Spectra Database*, 83 (NIST Atomic Spectra Database).