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STABLE AND INTENSE ^{48}Ca ION BEAM PRODUCTION WITH A MICROWAVE SHIELDED OVEN AND AN OPTICAL SPECTROMETER AS DIAGNOSTIC TOOL

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Abstract

The CAPRICE ECRIS installed at the High Charge Injector (HLI) of GSI produces highly charged ion beams from gaseous and metallic elements. A high demand of metal ions comes from the nuclear physics, material research, and Super Heavy Element group (SHE), and the most requested element, besides ^{50}Ti, is ^{48}Ca. When this chemical reactive material is deposited inside the plasma chamber at internal components the stability can be compromised. Furthermore, it is difficult to find a working point to guarantee a long-term stability as the oven response time and the reaction of the ECRIS are relatively slow. The monitoring by using an Optical Emission Spectrometer (OES) facilitates immediate reactions whenever plasma instabilities occur. For this reason, a real-time diagnostic system based on an OES has been installed at the ECRIS at HLI for routine operation during the beam-time 2020. The measured spectra revealed a parasitic oven heating by coupled microwaves often compromising the ion source performance. Therefore, a tungsten grid has been installed to shield the oven orifice from the coupled microwaves. The results in terms of ^{48}Ca beam intensity and stability are reported here.

INTRODUCTION

At the high charge state injector (HLI) of GSI highly charged ions are produced by a CAPRICE-type ECRIS. Up to 260 days of beam time per year were served from the ECRIS injector in the last decade. Figure 1 shows the total days of beam-times starting from 2008. In 2013 and 2017 the accelerator was on shut-down mode for maintenance or upgrade.

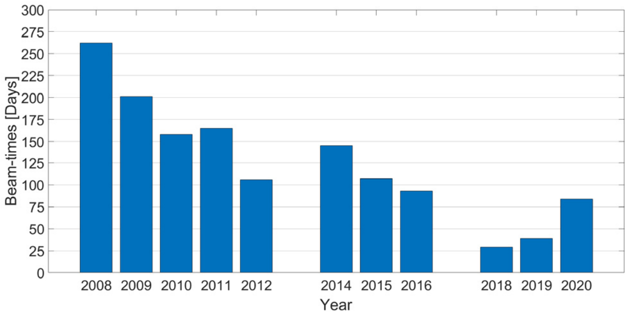

Figure 1: Total days of beam times in the last 12 years by the GSI ECRIS at HLI

A high demand of metal ions comes from the nuclear physics, material research, and Super Heavy Element (SHE) groups, and the most requested element is ^{48}Ca as shown Fig. 2. Up to 85 days per year of ^{48}Ca were requested in the last years. In order to produce the metallic ion beams with high efficiency and low material consumption, the evaporation technique is used at GSI by means of a resistively heated oven, the STO (Standard Temperature Oven). [1] The ion source performance in producing metallic ion beams has been optimized through the past decades to satisfy the demand of intensity and stability. However, when chemical reactive materials are deposited inside the plasma chamber and at internal components, the stability is compromised. Furthermore, it is difficult to find a working point for a long-term stability because the response time of the oven and the reaction of the ECRIS are relatively slow.

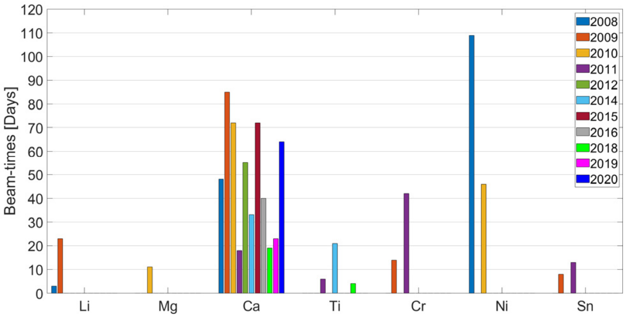

Figure 2: Total days of metallic ion beams produced in the last 12 years by the GSI ECRIS at HLI.

The Optical Emission Spectroscopy has been used to analyse the plasma parameters [2-3] and the continuous monitoring by using an Optical Emission Spectrometer (OES) may facilitate immediate reactions whenever plasma instabilities occur. For this reason, a real-time diagnostic system based on an OES has been installed at the ECRIS at HLI for routine operation and monitoring during the beam time. By means of the OES a parasitic oven heating by coupled microwaves was measured and in case of low melting elements of high vapour pressure like Ca it may compromise the ion source performance [4]. For this reason, the effect of the oven shielding was studied with the OES and a tungsten grid has been installed to shield the oven orifice at HLI during the Ca beam-times of 2020.

EXPERIMENTAL SET-UP

The description of the ion source and of the beamline are reported in [5] and references therein and the details of the

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STO are reported in [1]. The sample material has been filled into the STOs and then a tungsten grid has been installed to shield the oven head as show in Fig. 3. A tungsten mesh type 100 holes/inch and 0.0254mm wire with an open area of 81% was used. The geometry of the grid has been selected after several tests with different spacings carried out in December 2019 at the EIS (ECR Injection Set-up) testbench of GSI with ^{40}Ca. No material deposition or condensation was observed after the testing campaign. The microwave power coupled to the ECRIS during the Ca beamtimes was around 650 W at 14.5 GHz.

In order to early detect and prevent instabilities, a diagnostic tool, based on an OES, has been arranged. The setup is described in [4]. To measure the visible light spectrum, the Ocean Optics QE Pro spectrometer is used [6]. The main specifications include a 25 μm slit, a grating with 600 lines/mm calibrated at 500 nm and a 449-833 wavelength bandwidth determining a 0.95 nm optical resolution. During the beam-runs the optical spectra have been measured together with the plasma images recorded with a CCD camera.

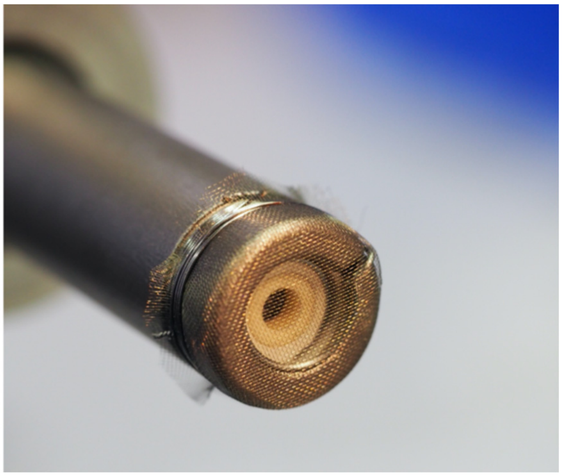

Figure 3: Microwave shielding grid at the oven orifice.

RESULTS AND DISCUSSION

At GSI, ^{48}Ca beams were requested to be delivered from the ECRIS at HLI from February to May 2020 for 64 days of total beamtime in four separate blocks. The ion source parameters were tuned to optimize the production of ^{48}Ca^{10+}. In table 1 the achieved beam parameters are reported. The maximum intensity achieved in 2020 has been 120 μA and a typical charge state distribution is shown in Fig. 4. With respect to the ^{48}Ca runs of the previous years a much more stable ion source behaviour has been observed implying a huge reduction of tuning intervention for optimization. The use of the tungsten grid improved the long-term beam stability. This result is shown in Fig. 5 where the ^{48}Ca^{10+} current measurement at the beam current transformer for almost 10 days, in April 2020, is reported.

Table 1: Ca Beam Runs in 2020: Main Achievements

Date	**^{48}Ca^{10+} intensity**	**Note**
19/02-04/03	90-120 μA	No on–call or intervention necessary
17/03-31/03	70-90 μA	Two on–call interventions
02/04-15/04	90-100 μA	Two on–call interventions
19/04-15/05	100-110 μA	No on–call or intervention necessary

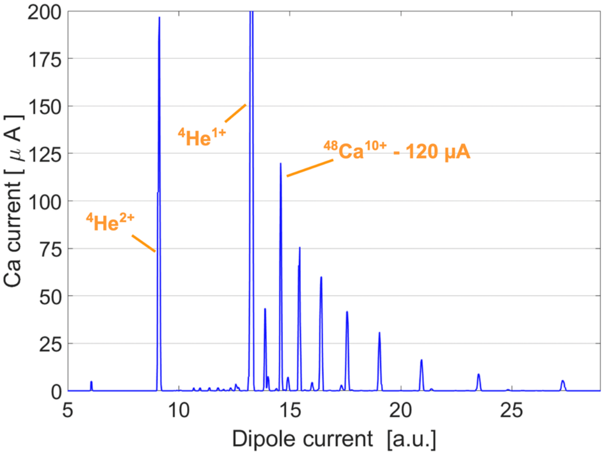

Figure 4: Ca charge states distribution optimized for Ca^{10+}.

The maximum intensity has been achieved at the very begining of ^{48}Ca production as observed for each beam run even in the past years. The intensity drop about 10-15% afterwards can be related to the contamination of the internal components due to the condensed material. A shift hof the intensity towards lower charge states has been observed as well. No ion source parameter has been tuned after the initial optimization and the oven setting has been slightly tuned on 7th and on 10th of April. The two events are underlined in Fig. 5. The first optimization required an increase of oven power in order to compensate the consumed material while the second one required a full ECRIS tuning since an increase of the oven temperature was detected.

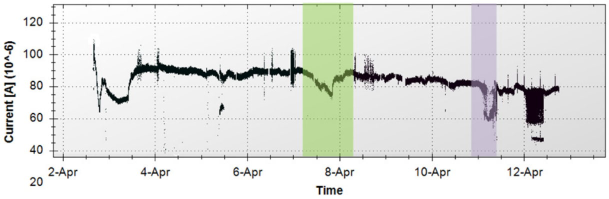

Figure 5: ^{48}Ca^{10+} intensity measured at the current transformer for 10 days.

In Fig. 6 the plasma images recorded during these two events are presented. The OES measurements were carried out at the same time frame when the plasma images have been recorded. The optical emission spectra of the plasma images corresponding to the three frames in the upper row of Fig. 6 are shown in Fig. 7. The optical spectra of the last two plasma images, corresponding to the second optimization event of the ECRIS are illustrated in Fig. 8.

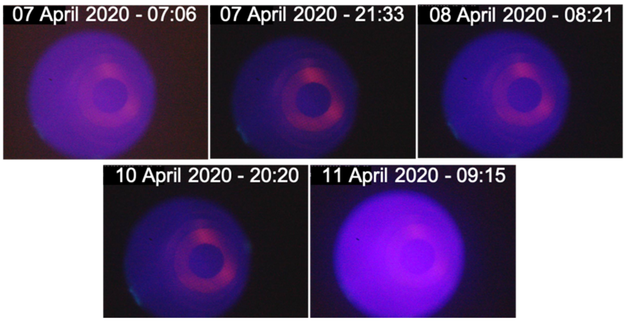

Figure 6: Plasma images recorded at the CCD camera when the optimizations of the ECRIS were requested.

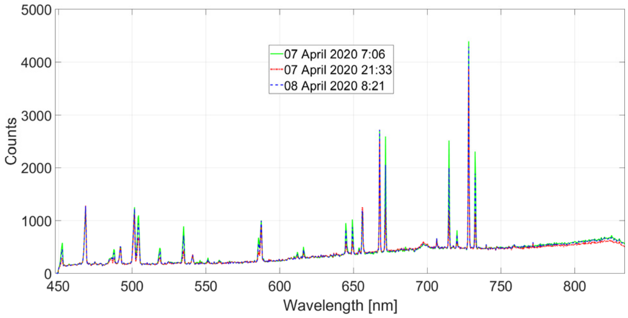

Figure 7: OES measurement at the upper time-frames of Fig. 6 during the first ECRIS optimization (07-08 April).

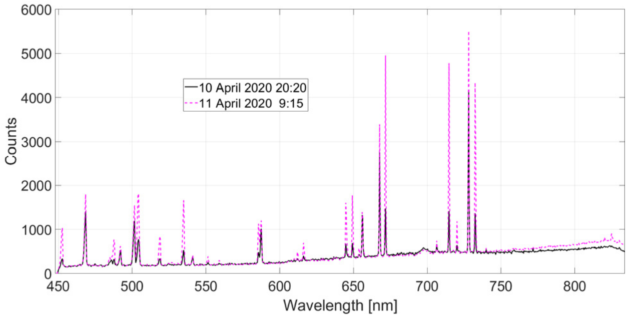

Figure 8: OES measurement at the lower time-frames of Fig. 6 during the second optimization (10-11 April).

With respect to the first optimization, at the second event occurred on the 11th of April an heating of the oven resulted in an increase of counts at higher wavelenghts.

This result ist more clear by analysing figure 9, showing the normalised intensity of the peak at 732 nm and at 827 nm and the integrated counts over the full spectrometer bandwidth. The dashed vertical lines identify the time frames when the plasma images and the optical spectra have been measured and reported. A rise of oven temperture occurred several times during the Ca beamtimes of previous years, but with the shielding grid this parasitic heating event was observed only once on 11th of April. Furthermore, the use of the shielding provided an improvement of the material consumption since the reduction of the parasitic heating events avoided the additional and unuseful material evaporation.

Nevertheless, finer meshes or thicker wires will be tested in order to improve the oven shielding to avoid any over heating. It is worth to report that no material condensation has been observed at the oven heads used for all the beamtimes confirming that the shielding can be routinely used even for longer beam time periods.

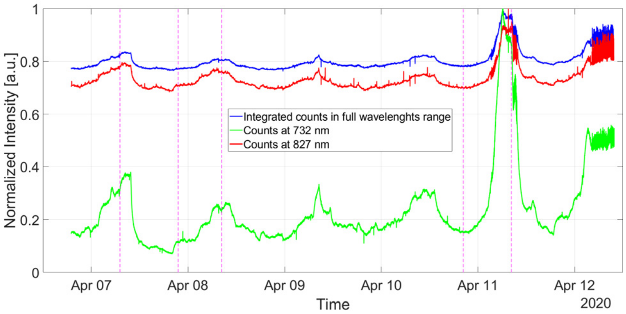

Figure 9: Normalised light intensity at different wavelengths recorded for 5 days (07-08 April)

CONCLUSION

The use of an OES as a diagnostic tool for routine operation of the CAPRICE ECRIS helps to recover the source performances much faster during the metallic ion beam production whenever optimizations are required or instabilities occur. This result has been confirmed during the last ^{48}Ca runs. The monitoring of the spectral components at certain visible wavelengths may help to prevent excessive optimization time.

The grid shielding of the oven head has improved the Ca ion beam production by an ECRIS in terms of stability, intensity and material consumption since the parasitic heating of the ceramic insulating material inside the oven head is strongly reduced.

In future it is anticipated to improve the light transmission between plasma and OES. A spectrometer with a wider range towards the infrared light spectrum would give the opportunity to measure the oven temperature in situ. This would lead to even better control of the evaporation rate.

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