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PRODUCTION OF METALLIC ION BEAMS WITH INDUCTIVE HEATING OVEN AT INSTITUTE OF MODERN PHYSICS*

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Abstract

A High-Temperature Oven (HTO) with inductive heating technology has been developed successfully in 2019 at Institute of Modern Physics. This oven features durable operation temperature of >2000°C inside the tantalum susceptor. By careful design the oven structure, material compatibility and thermal stress issues at high temperature has been successfully handled, which enables the production of >400 eμA U^{33+} with SECRAL-II. With necessary refinement, this type of oven could also be available with room temperature ECR ion sources, like LECR4 and LECR5. Some improvements in structure have been proposed in this year. The design and testing results will be presented in this contribution.

INTRODUCTION

Most of the advanced heavy ion accelerators need intense metallic ion beams, like MSU-FRIB needs 13 puA of U^{33+} and U^{34+}, RIKEN-RIBF needs 15 puA of U^{35+}, IMP-HIAF needs 20 puA of U^{35+}, and so on. To meet all these requirements, colleagues in the ECR community have developed several methods to produce enough metal vapour in ECR plasma, such as direct plasma heating, MIVOC, Sputtering, Metal oven, Laser ablation, etc. Direct plasma heating method is rarely used in ECR ion source now because the intensity and charge state are very limited and difficult to get very stable plasma. MIVOC is suitable for producing medium charge state ion beams. For sputtering method, it has the advantage of simple structure, and it's also suitable for long-term operation. But the disadvantages are also obvious, like difficult to get very high intensity and charge state. Laser ablation method has been shown to be capable of producing pulsed medium charge state metallic ion beams. But the charge state and reliability still need to be further improved. In general, metal oven method is still the best way to produce intense high-charge-state ion beams. As shown in Fig. 1, it is clear that, for refractory metals, the typical temperature to produce enough metal vapour (0.01–0.1 torr) in an ECR source is 1600–2000°C.

As we know, high performance resistive heating ovens have been developed in the ECR community for more than ten years, and some good results have been produced [1, 2]. But there are also several challenges, like high standard processing technology, strong Lorenz force, and so on. This could be more serious in the next generation ECR ion sources, like FECR and MARS, because the axial magnetic field at the injection side might up to 6 T. compared with a resistive heating oven, the most important feature of an inductive heating oven is that it's Lorenz force free when working in the high magnetic field environment.

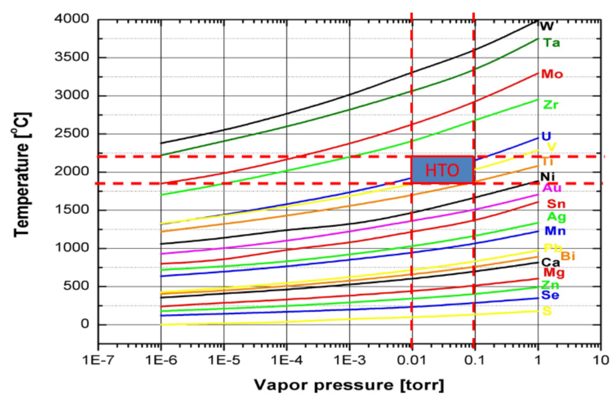

Figure 1: The temperature as a function of metal vapour pressure for refractory metals.

INDUCTIVE HEATING OVEN-2019

The structure of this inductive heating oven is similar to that of MSU [3]. It is composed of a susceptor, zirconia, inductive heating coils, water cooling system, and an AC power supply. The main difference is that a gap has been added between the tantalum crucible and zirconia, as shown in Fig. 2. With this gap, the crucible can only contact the zirconia at the ends, thus effectively avoiding the chemical reaction between each other at the high-temperature region and improving the working temperature and corresponding service life. The newly designed oven also has the following features: 1) end cover structure is designed for easy fixing; 2) Al_2O_3 instead of BN for outer shielding. All of these

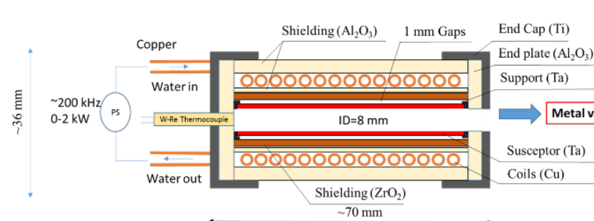

Figure 2: Schematic view of the inductive heating oven-2019.

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make the inductive heating oven-2019 become a reliable, flexible, and low out-gassing high-temperature oven.

Off-line and On-line Test

Figure 3 shows the off-line test platform for the inductive heating oven-2019 at IMP. The test result shows that the temperature of tantalum crucible can reach up to ~2000°C at a maximum AC power of about 1.2 kW. After the off-line test, we installed the oven on the supercon-ducting ECR ion source SECRAL-II, to produce intense high-charge-state uranium ion beams. With 24⁺ 18 GHz double frequency heating, some preliminary results have been produced with a total microwave power of 6.0 kW in 2019, such as 310 eμA of U^{35+}, 60 eμA of U^{42+}, 9 eμA of U^{50+}, and so on. Detailed information can be found in reference [4].

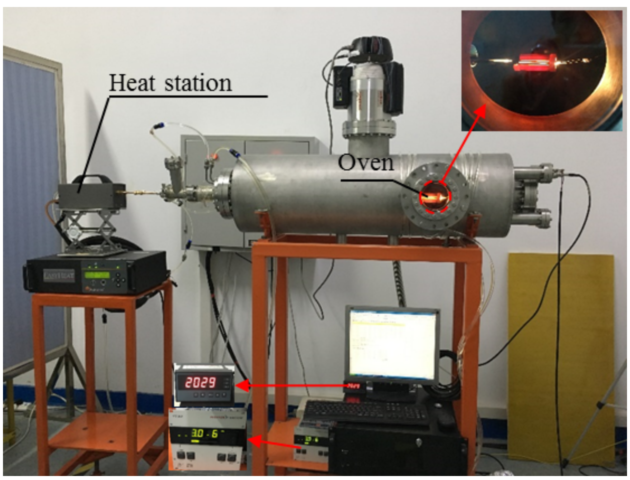

Figure 3: Off-line test platform for the inductive heating oven-2019 at Institute of Modern Physics.

Routine Operation for HIRFL-CSR

HIRFL-CSR has been operating for more than 10 years at IMP since 2007. It needs refractory metallic ion beams for different terminal requirements every year, like $^{27}Al^{8+}$, $^{56}Fe^{17+}$, $^{181}Ta^{35+}$ in 2019. For aluminum and iron, we use the inductive heating oven-2019 instead of the traditional oven. Intensities of 20–30 eμA for $^{27}Al^{8+}$ and 30–40 eμA for $^{56}Fe^{17+}$ have been produced on SECRAL-II ion source with 0.3–0.4 kW of inductive heating power and delivered to HIRFL-CSR for about one week to one month without interrupt, as shown in Table 1. Figure 4 shows long-term stability when delivering $^{56}Fe^{17+}$. For tantalum, we use the sputtering method. 40–60 eμA of $^{181}Ta^{35+}$ has been produced on SECRAL-II ion source with 3.9–4.5 kV negative sputtering voltage and delivered to HIRFL-CSR for more than three weeks without interrupt.

MINI-INDUCTIVE HEATING OVEN-2020

For standard inductive heating oven-2019, the diameter and length is 36 mm and 70 mm, which is suitable for superconducting ECR ion source SECRAL-I and SECRAL-II, but too large for a room temperature ECR ion source,

Table 1: Refactory Metallic Ion Beams Routine Operation for HIRFL-CSR in 2019

Ion	IHO Temp. [°C]	Iq [eμA]	Days
$^{27}Al^{8+}$	1300–1400	20–30	7
$^{56}Fe^{17+}$	1400–1500	30–40	32
$^{181}Ta^{35+}$	Sputtering method	40–60	21

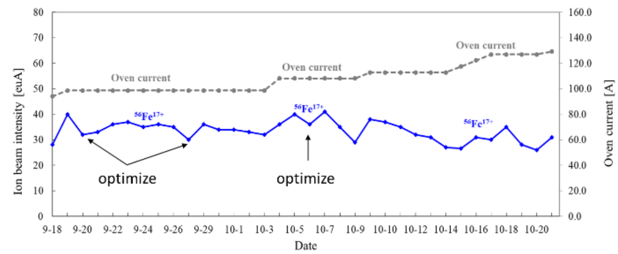

Figure 4: $^{56}Fe^{17+}$ routine operation for HIRFL-CSR with inductive heating oven-2019 in one month.

like LECR4 and LECR5 at IMP. To solve this issue, mini-inductive heating oven-2020 has been proposed this year. As shown in Fig. 5, it is similar to inductive heating oven-2019 in structure, but smaller in diameter and shorter in length. Similar crucible diameter has also been kept to provide enough loading capacity for long-term operation.

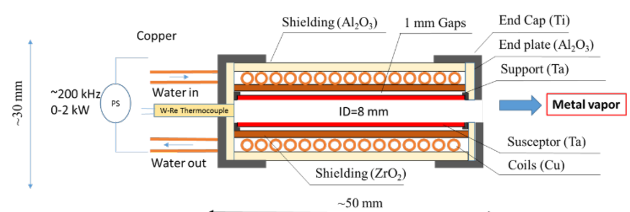

Figure 5: Schematic view of the mini-inductive heating oven-2020.

1st On-line Test

The mini-inductive heating oven-2020 was firstly installed on the room temperature ECR ion source LECR5, to produce intense highly charged calcium ion beams with calcium oxide directly. It is worth to mention that the ion source group at RIKEN has already produced ~50 eμA of $^{40}Ca^{11+}$ with CaO and high-temperature resistive heating oven in 2019 [5].

In the first test, the oven was located close to the plasma in order to utilize the contribution of plasma heating, as shown in Fig. 6. In fact, the plasma contributes too much, which leads to serious outgassing and instability. Only low-charge-state ion beams were produced, like 110 eμA of Ca^{3+}, 60 eμA of Ca^{4+}, and so on, as shown in Fig. 7.

2nd and 3rd On-line Test

To decrease the influence of plasma heating to the oven, we increase the distance between oven and plasma from 40 mm to 60 mm and 100 mm, as shown in Fig. 8. In the second test, plasma heating is still obvious, but much lower.

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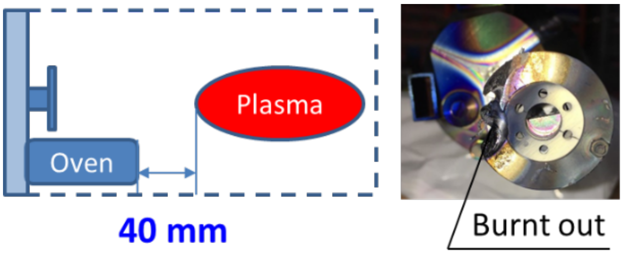

Figure 6: Layout of oven and plasma in the 1st on-line test and photo of oven after tuning.

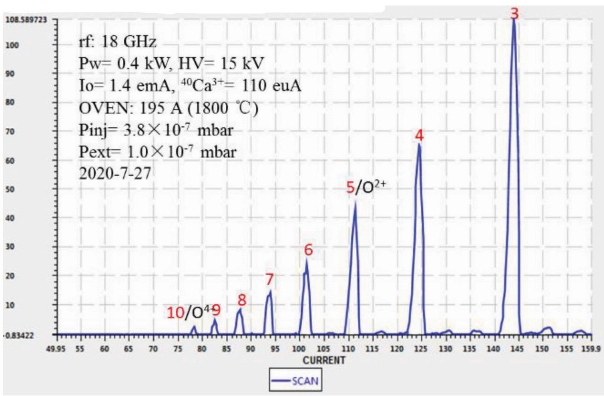

Figure 7: Typical spectrum when oven nearby the plasma in the 1st on-line test.

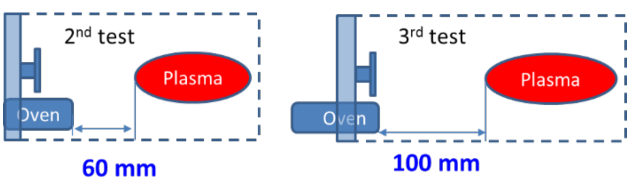

Figure 8: Layout of oven and plasma in the 2nd and 3rd on-line test.

Some medium-charge-state calcium beams have been produced, like 120 eμA of $^{40}Ca^{12+}$, 50 eμA of $^{40}Ca^{14+}$, and so on. In the third test, the oven is located far always from the plasma. Test results demonstrated that the plasma heating influence has been well controlled, and very high charge state calcium beams can be produced, such as 30 eμA of Ca^{16+}, 10 eμA of Ca^{17+}, etc. Figure 9 shows the typical spectrum when Ca^{12+} is optimized.

CONCLUSION

A new type of inductive heating oven with a special gap and fixing structure has been developed at the Institute of Modern Physics. Online test and routine operation have

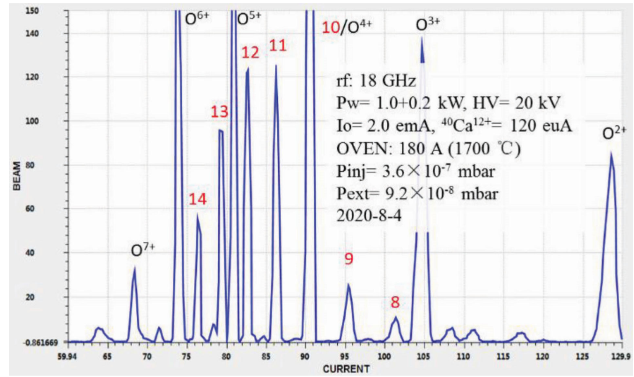

Figure 9: Typical spectrum in the 2nd on-line test.

shown that this type of oven can operate at 1600–2000°C for long-term operation without degradation and damage. With necessary refinement, the mini-inductive heating oven-2020 has been fabricated this year and applied to the room temperature ECR ion source LECR5. Some preliminary results have been produced with 0.6–0.8 kW of inductive heating power, like 120 eμA of $^{40}Ca^{12+}$, 50 eμA of $^{40}Ca^{14+}$, 30 eμA of $^{40}Ca^{16+}$, etc.

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