METAL ION BEAM PRODUCTION WITH IMPROVED EVAPORATION OVENS

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Abstract

Most of the ion beams delivered by the ECR ion sources at the GSI accelerator facilities are produced from materials in the solid state, which must be transformed into the gaseous state to feed the plasma. The well established method of thermal evaporation has been used by means of two types of resistively heated ovens for metals and solid compounds. The main goal of development is to improve their versatility in terms of lifetime, durability, efficiency, and extended temperature range. Recent investigations and developments include the use of alternative materials for oven components. The main focus has been on the further development of the high temperature oven. A modular construction with improved mechanical dimensional accuracy for more precise and easier mounting has been established. Its optimization for stable long time operation has been continued leading to a lifetime of 6 days for evaporation of Ti at 1750°C. Furthermore the temperature limit could be extended to 2300°C. In addition to the improvements in evaporation technology the technique of microwave frequency tuning could be successfully applied for metal ion operation leading to enhanced ion beam intensities.

INTRODUCTION

A great variety of ion species is required at the GSI heavy ion accelerator facility. More than 85% of the natural elements are solid at room temperature and must be transformed into the gaseous state to feed the plasma. Several methods like thermal evaporation, plasma heating, ion sputtering, laser ablation or producing metal ions from volatile organic compounds (MIVOC) can be applied. At GSI the evaporation technique using ovens has been preferred because it resembles closely the operation with gases [1]. It has been used for two decades to produce ion beams from many different materials with the CAPRICE type ECR Ion Source (ECRIS). The basic requirements of operation are long time stability, long operation periods without maintenance, constant beam parameters and low material consumption when using rare isotope materials. According to semi-empirical scaling and experimental experience a vapour pressure of about 10^{-3} mbar is suitable for evaporation into the plasma and to extract stable ion beams of sufficient intensity.

STANDARD OVEN

The resistively heated standard oven (STO, Fig.1) is mostly used for the production of metal ion beams in routine operation with the ECRIS at GSI. The STO is optimized for temperatures between 300°C and 1500°C.

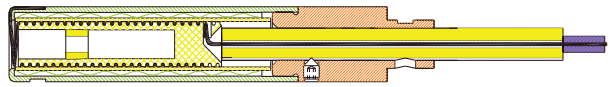

Figure 1: STO - GSI standard oven (yellow: Al_2O_3; green: Ta; orange: Mo; violet: CuBe2)

For $^{54}Cr^{8+}$ it was investigated whether the lifetime of the oven can be increased by increasing the initial amount of ^{54}Cr sample material. It turned out that the lifetime increases with the charge to some extent, however, the material consumption also increases. It became evident that an optimum charge of sample material exists giving the best compromise between oven lifetime and material consumption. The overall consumption of ^{54}Cr sample material was 4 mg/h on average with a range of fluctuation between 2 mg/h and 6 mg/h for the particular charges. Figure 2 shows a typical mass/charge spectrum of the extracted ion beam. Besides ^{54}Cr and He (auxiliary gas) it shows a very low amount of contaminations and confirms the very high degree of enrichment of the ^{54}Cr material.

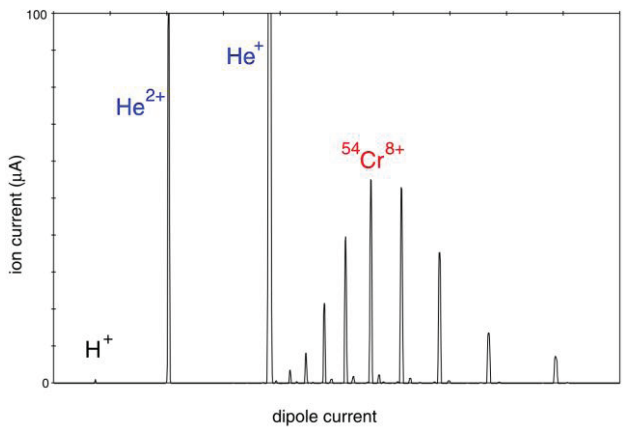

Figure 2: Typical mass/charge spectrum of ^{54}Cr.

TITANIUM BEAM WITH STO

The investigations on the development of a ^{50}Ti beam for experiments of the Super Heavy Element (SHE) program were extended by exploring 3 alternative approaches. Besides thermal evaporation of titanium with the STO another type of resistively heated oven was investigated. This type of oven had been developed for the thermal evaporation of materials at very high temperatures (HTO, Fig. 3) [1].

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Furthermore the evaporation of chemical Ti-compounds at low temperatures was explored but did not lead to a useful method.

The normal version of the STO is equipped with alumina (Al_2O_3) ceramics as support for the heating wire and as container for optional crucibles. However, alumina is not resistant against molten Ti and its vapour, which show very high chemical reactivity with almost any material. After exploring various oven configurations using different ceramics materials and refractory metals it turned out that only yttria (Y_2O_3) based ceramics can provide improved resistance. Commercially available yttria ceramics showed insufficient mechanical form stability at the required temperature. An optimization of the ceramics sintering processes including different ceramic stabilizers could considerably improve the durability. Thus the operating conditions of the modified STO for Ti could be improved. An improved thermal front shielding of the STO by multi-laminated and corrugated Ta foils led to an optimized axial temperature function, which lowered the heating power to achieve the same temperatures.

TITANIUM BEAM WITH HTO

Contrary to the STO the design of the HTO avoids any ceramics in the hot volume. Instead it utilizes a free heater helix supported only at its ends. All parts in the hot volume are made from Ta, W or W compounds. This circumvents the specific problems arising from the use of ceramics and so the application of the high temperature oven turned out to be the most promising approach. The disassembling of parts after operation with very high temperature leads to problems. In order to optimize the HTO for routine operation its modular construction was improved in mechanical dimensional accuracy for more precise and easier mounting and dismounting. The use of a special W compound containing 2% of La_2O_3 for crucibles and for furnace facilitates their ductility and machinability. However, its drawback is the evaporation of La out of the metal matrix at very high temperatures, which implies the use of W crucibles under such conditions.

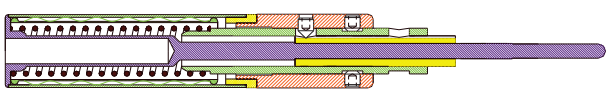

Figure 3: HTO - GSI high temperature oven (yellow: Al_2O_3; green: Ta; orange: Mo; violet: W).

Various experiments were performed with the HTO using natural Ti for most runs. For final confirmation, however, ^{50}Ti sample material had to be used. In addition the evaporation of TiO_2 was investigated, which avoids the problems related to the chemical reactivity of pure Ti at high temperatures. According to the required vapour pressure for the evaporation of TiO_2 the temperature limit of the high temperature oven could be successfully extended near to 2300 °C corresponding to 560 W of electrical heating power (Fig. 4).

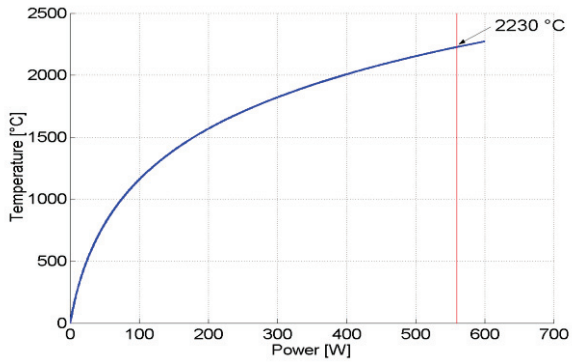

Figure 4: HTO temperature as function of heating power (measured up to 2050°C; extrapolated above 2050°C).

However, this high operating temperature reduces the lifetime of the oven. Therefore it appeared to be more favourable to use pure titanium as sample material at evaporation temperatures between 1750 °C and 1800 °C.

Several successful runs could be performed with natural titanium material and with enriched material. It could be demonstrated that the material processed in the GSI target laboratory by chemical reduction of enriched $^{50}TiO_2$ material is usable. The charge state distribution was optimized for Ti^{8+}, which is suitable for injection into the linear accelerator. The expected intensities of more than 50 µA could be easily achieved at high level of beam stability. Figure 5 shows a typical spectrum for a ^{50}Ti run.

The lifetime of the oven is related to the applied heating power, which is also of major influence on the average ion beam intensity. At a typical lower level of heating power of 250 W (corresponding to 1750 °C) a lifetime of 6 days is obtained. This value is reduced, when the heating power is increased. The high temperature oven in its present development status is prepared for routine operation at the accelerator.

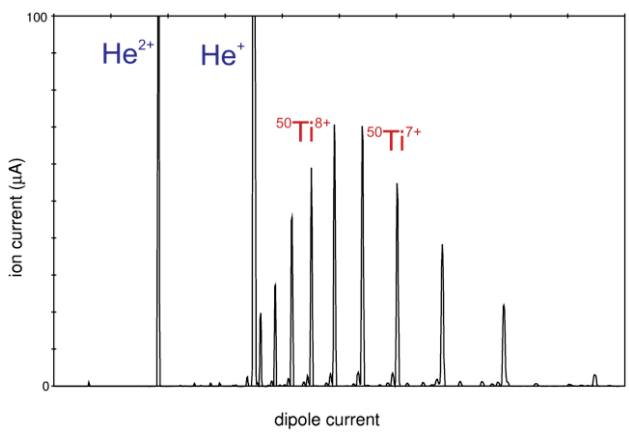

Figure 5: Typical mass/charge spectrum of ^{50}Ti.

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MICROWAVE TUNING

The new Facility for Antiproton and Ion Research (FAIR, [2]) that will be set up in the next years at GSI implies upgrades of the existing accelerator facility which will be used as injector machine for FAIR. For the ECRIS an increase of accelerated ion charge state is desired together with a considerable increase of ion beam intensity.

It has been demonstrated that a frequency tuning of the microwave injected into the ECRIS using a travelling wave tube amplifier (TWTA) can provide a considerable increase of the intensity of metal ion beams (at selected frequencies) like in the case of gaseous elements [3].

The test was carried out by replacing the Klystron microwave generator working at 14.5057 GHz by a TWTA driven by a frequency variable synthesizer. It was initially set at 14.5057 GHz and a power around 250 W was provided to the ion source. At a heating power of the oven of around 230 W a sufficiently stable ion beam of Ti^{8+} was obtained. Then the microwave frequency was swept in the frequency range from 12.5 to 16.5 GHz exhibiting a pronounced intensity variation of Ti^{8+} and Ti^{11+}, respectively.

The ion current of Ti^{11+} at the initial frequency was around 13 µA while during the sweep some frequencies were indentified where this current was increased. For instance at 13.725 GHz the current of Ti^{11+} was around 34 µA.

A comparison of the mass/charge spectra at these two frequencies shows a shift of the charge state distribution leading to a considerable intensity gain for the higher charge states. This is demonstrated e. g. for the ratio of Ti^{11+} and Ti^{8+} in Fig. 6 and Fig. 7, respectively. These spectra are obtained with identical source settings and oven heating. After almost 12 hours of operation at 13.725 GHz the beam was stable and the ion source worked continuously without any adjustment of the parameters with the exception of the oven power which was increased for compensating the consumed material. A frequency sweep was carried out again and it was possible to measure the highest intensity of Ti^{8+} current of more than 90 µA at 14.5438 GHz (Fig. 8).

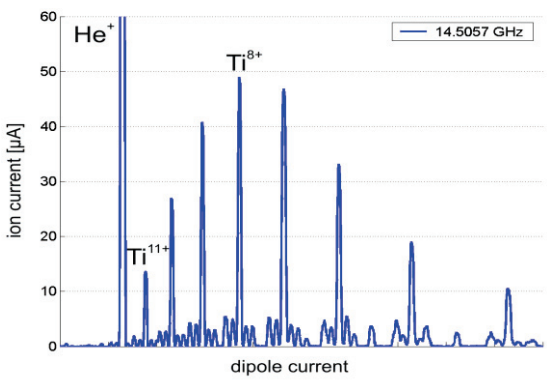

Figure 6: Mass/charge spectrum of natural Ti (forward power = 250 W; reflected power = 28 W; HTO heating power = 234 W).

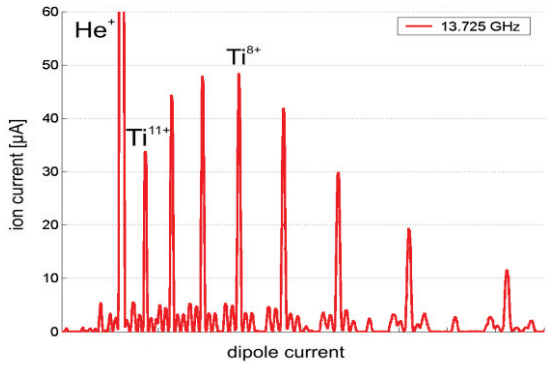

Figure 7: Mass/charge spectrum of natural Ti (forward power = 250 W; reflected power = 1 W; HTO heating power = 234 W).

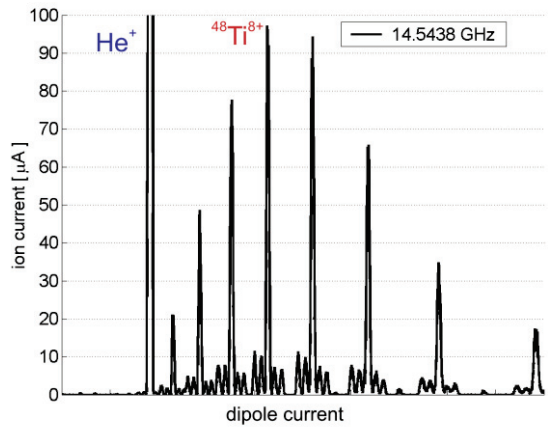

Figure 8: Mass/charge spectrum of natural Ti (forward power = 234 W; reflected power = 95 W; HTO heating power = 262 W).

These experiments demonstrated that frequency tuning can be a powerful method to increase the ion beam intensity of the highest charge states for metal ions.

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