Li and Ca ION BEAMS PRODUCTION

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Abstract

During the last year our design efforts have been focused on the production of $^{7}Li^{2+}$ and $^{48}Ca^{6+}$ ion beams from ECR ion sources DECRIS-14-2 and ECR-4M respectively. In both cases the required beam intensities should exceed 100 eμA. For that purpose a new microoven for the evaporation of metal samples has been designed. Relatively high ion currents required in the case of Li and Ca beams have risen the problem of the working material consumption. To reduce this problem a thin cylindrical tantalum sheet thermally insulated from the water cooled chamber wall has been installed inside the ionisation chamber. During the source operation the sheet was heated by the plasma electrons and microwaves. In a long-term operation with the ion currents in the range of 100 ÷ 200 eμA the Li and Ca consumption was less than 0.7 mg/h. The ion beam was stable and only a small addition of support gas was required.

1 Introduction

During the past few years the performance of the cyclotrons in the FLNR JINR was upgraded to a great extent. Two axial injection systems for the U-400M and U-400 cyclotrons were constructed and put into operation in the beginning of 1995 and in the second half of 1996, respectively. The first one uses the ECR ion source DECRIS-14-2, which was designed and built in Dubna [1]. The axial injection system for the U-400 cyclotron operates with the ion source ECR-4M, supplied by GANIL [2].

According to the scientific program of the FLNR JINR twokinds of ion beams were the most important for physical experiments in 1997 and 1998. The first one, $^{7}Li^{2+}$ beam from DECRIS-14-2 + U-400M cyclotron for the ^{6}He secondary beam production, is to be used in the experiments on the High Resolution Channel of Radioactive Beams. The second one is $^{48}Ca^{6+}$ beam from ECR-4M + U-400 cyclotron for the superheavy elements program. For both cases beam intensities of more than 100 eμA and longterm stability are required.

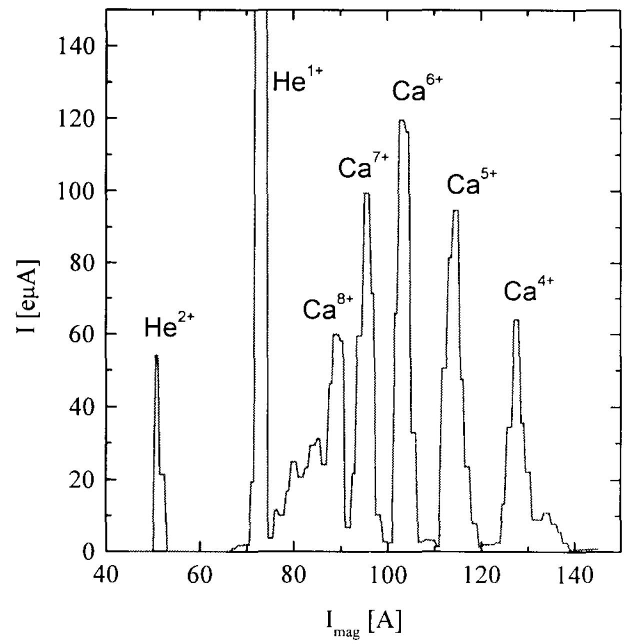

Figure 1: The ^{48}Ca ion spectrum, optimised for Ca^{6+}.

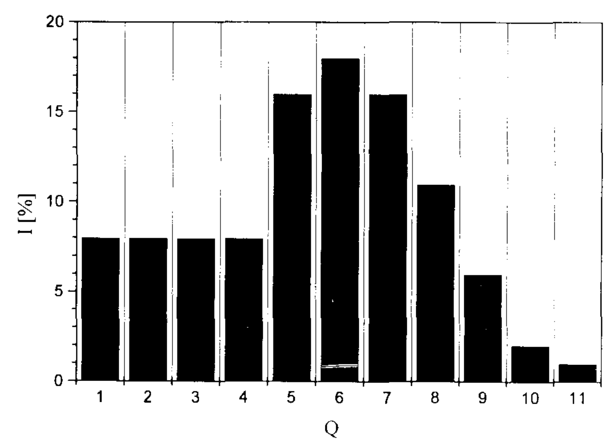

Figure 2: Number of particles, in percents, in the Ca ion beam for different charge states.

2 Efficiency

Relatively high ion currents required in the case of Li and Ca beams (over 100 eμA) have risen the problem of the working material consumption. During the long term experiments, especially in the case of the ^{48}Ca enriched isotope this problem became very important due to the high price of the working material. Since we are interested in Ca^{6+}, let us define the total efficiency of the Ca beam production ε_{tot} as a ratio of the number of the extracted Ca^{6+} ions and the total number of evaporated Ca atoms per second, taking into account also a possibility of collecting some part of the Ca absorbed on the cool discharge chamber walls. Then:

$$\varepsilon_{TOT} = \frac{N(Ca^{6+})}{N_{int} - N_{col}}$$

where N_{int} is the number of Ca atoms introduced into the ion source and N_{col} is the number of Ca atoms collected after running the source. It is well known that usually only small part of the solid material introduced to the discharge chamber of the ion source can be transformed to the ion beam. If k_b is the part of Ca extracted from the ion source as an ion beam, then $k_{is} = (1 - k_b)$ is the part of Ca which is left inside the ion source. So, the equation for ε_{tot} can be written as:

$$\varepsilon_{tot} = \frac{\lambda \bullet k_b}{1 - k_{is} \bullet \varepsilon_{col} \bullet \varepsilon_{reg}}$$

where ε_{col} and ε_{reg} are the collection efficiency and the regeneration efficiency of Ca, λ is the part of Ca^{6+} ions in the Ca ion beam.

The typical spectrum of ^{48}Ca ion beam extracted from ECR-4M during the routine operation is presented in Fig. 1. Figure 2 shows the number of particles, in percents, in the ^{48}Ca ion beam for different charge states. Here we assumed that for lowest charge states, such as Ca^{1+}, Ca^{2+} and Ca^{3+} the number of particles are the same as for Ca^{4+}. Taking into account that in our case $\lambda = 0.18$ it is possible to calculate the total efficiency of the Ca^{6+} ion beam production for different values of k_b and $\varepsilon_{col} \times \varepsilon_{reg}$. As is shown in Fig. 3

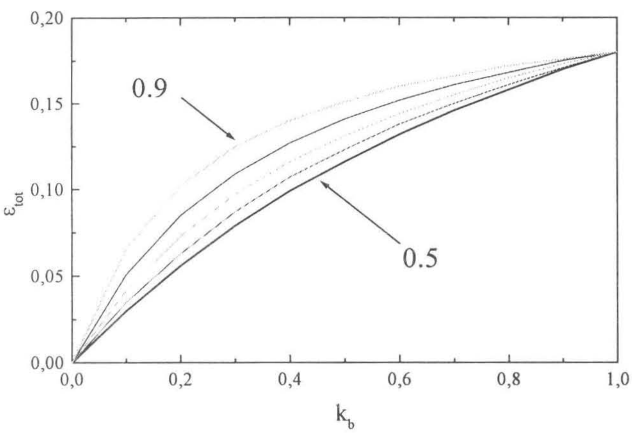

Figure 3: Total efficiency vs k_b for different $\varepsilon_{col} \times \varepsilon_{reg}$.

the total efficiency strongly depends on the percentage of the evaporated Ca atoms transformed into the ion beam. For example, for the case in which $k_b = 0.5$ the total efficiency will be approximately three times higher compared with the case in which $k_b = 0.1$. It is also clear that the total efficiency very much depends on the efficiency of the collection and regeneration of Ca absorbed on the discharge chamber wall.

3 Production of Li and Ca ion beams

Significant progress in metal ion production became possible owing to the development of a new microoven for the evaporation of metal samples. Our design efforts were focused on ensuring the reliability and long lifetime of the microoven itself according to the demands of the experiments with the Li and Ca ion beams. The new oven (see Fig. 4) consists of a stainless steel body, ceramic insulators and a special heater. The heater itself consists of NiCr wire with mineral insulation enclosed in a stainless

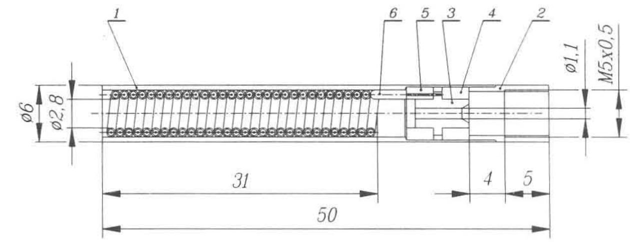

Figure 4: Microoven. 1,2 - body, 3 - electrical connector, 4,5 - ceramic insulators, 6 - heater.

steel screen. The maximum temperature for the heater is about 900^0C. For this reason stainless steel was chosen for the manufacturing of the oven's parts. The absence of expensive alumina insulators makes this oven very cheap. A stainless steel crucible with solid samples may be placed directly inside the heater. A metal vapor feed may be sensitively controlled by the heating current. Since the wire of the heater is protected by the screen, the lifetime of the oven seems to be long enough. By now the oven has worked for about 1300 hours without any damages.

Since only a small fraction of the evaporated metal really goes into the beam the rest is condensed at the water cooled chamber walls. One possible way to change this balance is to use a hot screen with a temperature high enough to evaporate metal atoms condensed on it. This screen should not influence correct functioning of the ion source. In our case this condition is not so critical because the required charge state of Ca ions is not so high. For this purpose we install a thin cylindrical tantalum sheet inside the ionization chamber. The diameter of this screen is few millimeters smaller than the diameter of the discharge chamber and it is thermally insulated from the water cooled chamber wall. During the source operation the screen is heated by the plasma electrons and microwaves. As a result, the more the feed of microwaves, the higher the temperature of the screen. Measured and calculated temperatures of the screen are shown in Fig. 4.

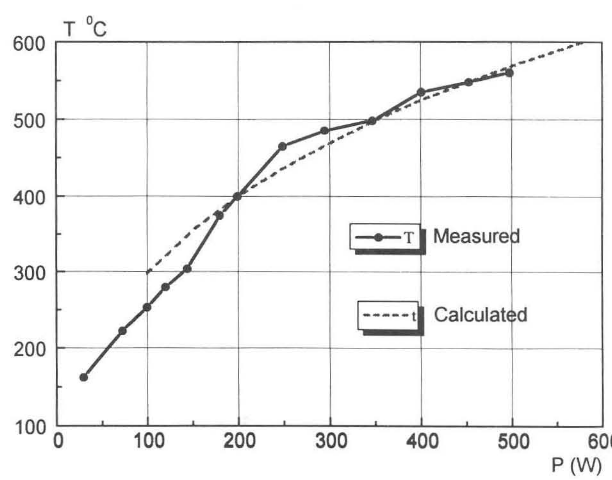

Figure 5: Measured and calculated screen temperature vs microwave power.

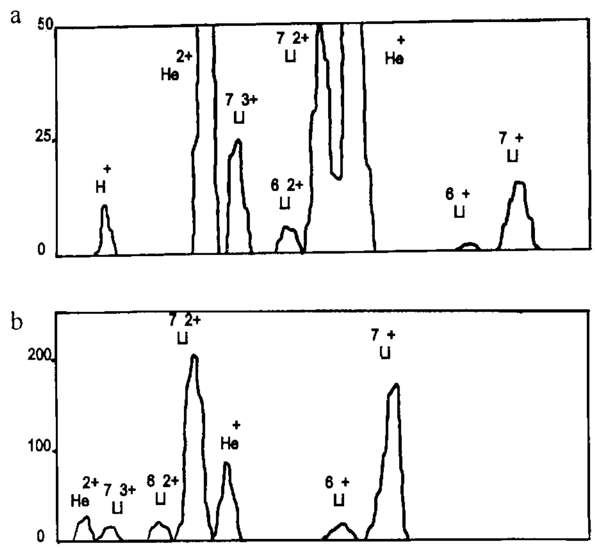

Figure 6: The Li ion beam spectrum, optimized for Li^{2+} (a - without a screen, b - with a screen).

This new method of producting ion beams of metals and compounds with low evaporation temperatures, such as Li, Mg, Ca etc. which include combination of a microoven with a hot screen was originally tested using Li at the ECR ion source DECRIS-14-2.

According to the measurements, presented in Fig. 5 the microwave power in the range from 200 to 300 W is enough to heat the screen to the temperature of more than 400 ^{0}C. With this temperature, the Li vapor pressure of the order of 1×10^{-3} mbar can be reached.

These tests showed that the screen does not disturb the plasma very much. It was possible to produce about 290 emkA of Li^{2+} (Fig.3, b) with the microwave power of 300 W. The beam was very stable and only a very small addition of the He was required. In a long-term operation the Li consumption was less than 0.7 mg/h. As shown in Table 1, the yield of Li^{2+} when the combination of the microoven with a hot screen was used is more than five times higher compared with the case without a screen.

It is important to note that in experiments on the Li ion beam production we never optimized the ion source to minimize the working material consumption. Nevertheless, according to our estimations, in the case with the hot screen part of evaporated Li atoms transformed into the ion beam increased up to aproximately 20 % compared with the case without a screen when more than 95% of atoms were absorbed on the chamber wall.

Table 1. Yields (eμA) for Li from DECRIS-14-2.

Q	1+	2+	3+	Notice
^{7}Li	15	50	25	no screen
^{7}Li	180	290	50	with screen

In the case of ^{48}Ca the problem of total efficiency, including the ion beam production, the beam transport and acceleration becomes most important. As is shown in Fig. 1 it was not very difficult to produce the $^{48}Ca^{6+}$ ion beam with

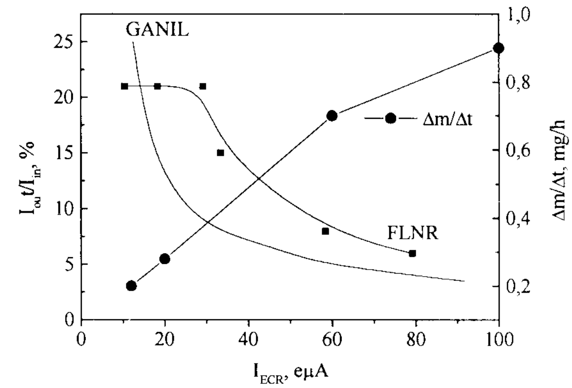

Fig.7 Experimental results for the bunching effect and consumption of metallic ^{48}Ca versus the ion beam intensity from the ion source

intensity of more than 100 μA. At the same time it was decided to take into account the efficiency of a buncher versus the ion beam intensity, which has been obtained by the GANIL [3] and FLNR [4] groups.

Fig. 7 shows that for the optimal ^{48}Ca consumption the ion beam intensity should be of about 30 ÷ 40 eμA. For this case a comparatively low consumption (of about 0.4 mg/h) was reached. It means that introducing about 1.4×10^{15} pps into the discharge chamber we produce about 2.8×10^{14} pps as a total ^{48}Ca beam including about 6×10^{13} pps of $^{48}Ca^{6+}$. Taking into account the beam transport efficiency from the ECR ion source to faradey cup (of about 0.6) leads to the value of about of 7% of the ion source efficiency for Ca^{6+} production.

It is also possible to estimate the percentage of evaporated Ca atoms which were transformed to the ion beam. Some simple calculations give the value of about 30%. According to the numerical simulation which is shown in Fig. 3 the total ion source efficiency including collection and regeneration of absorbed on the chamber wall Ca will be in the range of 8÷12 %.

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References

[1] A.Efremov et al., Rev. Sci. Instr., V 69, N 2, 1998, p.662

[2] R.Leroy et al., Proc. of the 12th Int. Workshop on ECR Ion Sources, RIKEN, 1995, INS-J-182, p.57

[3] E.Baron et al. Proc. of the 11th Intern. Conf. on Cyclotrons and their Applications, ed. by M.Sekiguchi, Y.Yano, K.Hatanaka (October 13-17, 1986), Ionics Publication Company, Tokyo, Japan 1986, p.234

[4] V.B.Kutner et al. This Proceedings