STATUS REPORT OF THE JYFL-ECR ION SOURCES

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Abstract

Ion beam “cocktails" are mixtures of ions with near-identical charge-to-mass ratios. In conjunction with the JYFL-ECRIS, the K130-cyclotron acts as a mass analyzer: the switch from one ion to another within the same cocktail is simple and fast. This capability is especially useful in the study of single event effects (SEE) in space electronics. The MIVOC beams have an important role in the cocktails.

A major technical modification since the construction (in 1990) of the JYFL-ECRIS was made in January 98: a negatively biased disc replaces now the first plasma stage.

Due to the requirements of ion beams with higher charges and heavier elements than the present JYFL-ECRIS can produce, JYFL decided to begin a design and construction project of a new ECR ion source. The project aims for a source that is based mainly on the design of the 14 GHz AECR-U source at the Lawrence Berkeley National Laboratory. Some modifications made to a similar source under construction at the National Superconducting Cyclotron Laboratory, MSU will be utilized here.

1. Introduction

In 1997-1998 the JYFL-ECR Ion Source [1] at the Accelerator Laboratory, University of Jyväskylä was used more than 12000 plasma-on hours. Over 90% of this time ion beams were injected into the K130-cyclotron for use in accelerator based physics. The main part of the research at the accelerator has concentrated on probing extreme states of atomic nuclei. Because the laboratory offers good conditions for applied science a special program on transferring accelerator based technologies to commercial products has been initiated. This includes the direct use of the laboratory’s research capabilities and the knowledge acquired from the laboratory’s technical and scientific programs to carry out research and development projects. One application arises from versatile capabilities of the JYFL-accelerator-ion-source combinations to produce proper beams for the study of radiation effects on materials. Especially for this study different ion beam cocktails have been developed at the JYFL-ECRIS.

The MIVOC beams have an important role in the applied cocktails. In this contribution results of such beam developments are presented. The present status of all the MIVOC beams available are reviewed. A development in one technical issue is shortly discussed. A real improvement in the ion beam collection will be achieved in near future when the new 14 GHz ECRIS is in operation. Then two independent ECR sources will enable a continuous beam development at one of the ECR sources.

2. Ion beam cocktails

Ion beam “cocktails” are used when several ion beams with nearly the same A/q-ratio are needed during a single experiment. In the case of the first ion beam cocktail with the JYFL-ECRIS, the oxygen and argon gases were mixed into the gas feed line (Fig.1). At the same time magnesium and iron ion beams were produced using the MIVOC technique. Magnesocene and ferrocene compounds were put into the same MIVOC chamber. Due to a small difference in A/q-values all these elements could be transported and injected simultaneously into the cyclotron, and accelerated there.

A transfer from one element in the cocktail beam to another one is fast, takes place in minutes, and is carried out by fine-tuning the cyclotron magnetic field. In the described experiment, all the adjacent ion peaks have a relative difference within 0.03%. On the other hand the relative resolution of the cyclotron is 0.05% which means that these ion peaks are well separated for further transportation and

use in the experiment. Fig.1 shows intensities and positions of the $^{16}O^{2+}$, $^{24}Mg^{3+}$, $^{40}Ar^{5+}$ and $^{56}Fe^{7+}$ ions measured at the Faraday cup outside the cyclotron.

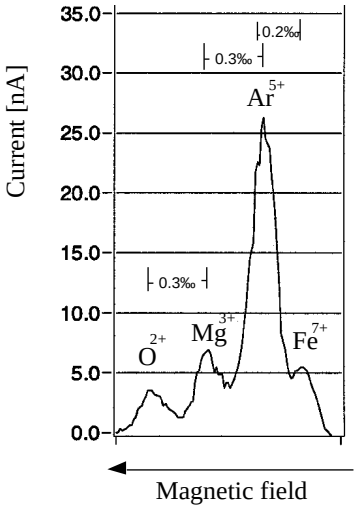

Fig.1. A/q spectrum measured outside the cyclotron. Ions shown in the spectrum were injected into the cyclotron simultaneously.

The French company Matra Marconi Space applied the above ion beam cocktail on semiconductor memories with known SEE (single event effects) sensitivity for the test and verification of a new measuring station RADEF [2] at JYFL.

Later Daimler-Chrysler Aerospace GmbH of Germany has used this setup to study irradiation effects on special chips intended for use in space electronics. The most useful ion beam cocktail for this purpose, so far has turned out to be a mixture of isotopes of the $^{12}C^{2+}$, $^{30}Si^{5+}$, $^{54}Fe^{9+}$, $^{84}Kr^{14+}$, and $^{132}Xe^{22+}$ ions which have $A/q \approx 6$. The first three isotopes were delivered from the MIVOC chamber. Compounds composing of natural elements were used.

For the ion beam cocktails all gaseous elements from H to Xe are available. The non-gaseous elements produced so far are C, Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Cu, Zn and Ge. The aluminum, calcium and copper atoms are vaporized in a miniature oven [3] and the zinc atoms are fed via a sputter method [4]. The rest are delivered from the MIVOC chamber.

3. Present MIVOC beams

There are now 20 different isotopes available for production of the so-called MIVOC beams. The MIVOC-method (Metal Ions from VOlatile Compounds) is a rather simple way to make certain ion beams from metals or solids [5, 6]. At an ECR ion source the MIVOC enables production of highly charged solid ion beams at room temperature conditions. In this technique vapors of volatile compounds having solid atoms in their molecular structure are used to release solid elements. The vapor pressure needed is typically of the order of 10^{-3} mbar or higher. Compounds are placed in a small vacuum chamber connected to the plasma stage of the ECR ion source. From there the vapor of the compound is allowed to diffuse into the source. Decomposition and ionization of the compound then take place in the gas-mixed plasma.

Table 1 lists atoms of the MIVOC ion beams which have been made from the compounds in the second column. The third column presents availability of the compounds and their form at room temperature.

Atom	Compound	Availability / form
B	$C_2B_{10}H_{10}$	c / s
C	all compounds	c / s, l
Mg	$Mg(C_5H_5)_2$	h-m / s
Si	$Si[Si(CH_3)_3]_4$	c / s
Cl	$TiCl_4$	c / l
Ti	$TiCl_4$	c / l
V	$V(C_5H_5)_2$	c / s
Cr	$Cr(CO)_6$	c / s
Fe-54	$^{54}Fe(C_5H_5)_2$	h-m / s
Fe	$Fe(C_5H_5)_2$	c / s
Co	$Co(C_5H_5)_2$	c / s
Ni	$Ni(C_5H_5)_2$	c / s
Ni-60	$^{60}Ni(C_5H_5)_2$	h-m / s
Ge	$Ge(CH_2CH_3)_4$	c / l
Mo	$Mo(CO)_6$	c / s
Ru	$Ru(C_5H_5)_2$	c / s
Sn		
I	I_2	c / s
W	$W(CO)_6$	c / s
Os	$Os(C_5H_5)_2$	c / s

Table 1. Atoms with their origins used as MIVOC ion beams. Also availability and form of compounds are presented (c = commercial, h-m = home-made, s = solid, l = liquid).

The MIVOC in its role has turned out to be both simple and effective. A drawback of the method is carbon released from the compounds. It tends to contaminate the plasma chamber walls. In long time use this may decrease intensities of ion beams. To minimize the consequences of this effect the plasma chamber

is usually lined with a removable aluminum foil. Also, on handling of chemical compounds attention should be paid to the safety rules. Recently MIVOC beams have been used and developed in numerous laboratories [7-17].

4. Modification of JYFL-ECRIS

A major technical modification since the construction of the JYFL-ECRIS (Fig.2) was replacement of the first plasma stage by a negatively biased disc.

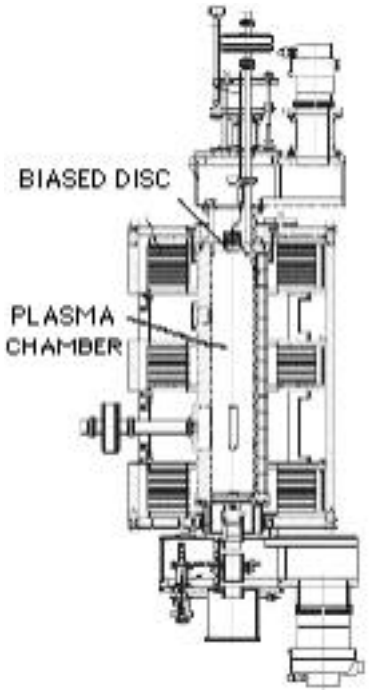

Fig.2. The JYFL-ECRIS operates now as a one stage source.

Currently one year's experience with the modified source has verified the new structure to be advantageous: The source is much more straightforward to use and good operating conditions are well repeated. Earlier tuning of the source was much more strict because the ECR surface easily went into touch with the walls of the first stage chamber. This resulted in instabilities.

The effect of the biased disc is typically 10-15% gain in the beam intensity. More important is its ability to stabilize the source plasma. The disc is in a fixed position which may not be optimal due to the present mechanical structure of the source. A real advantage in the operation is the new magnetic field configuration which can be used for all kinds of beams, gases and solids. The only draw-back in the new structure seems to be the complex installation of the upper part of the source.

A real test for the source reliability and stability was carried out on August 98. Then a three weeks continuous beam of $^{48}Ca^{9+}$ was run to the JUROSPHERE experiment at the RITU facility. The intensity in the target was the required 100 nA and the average consumption of ^{48}Ca in the miniature oven was a reasonable 0.08 mg/h. The beam set stayed stable without additional tuning over that time.

5. JYFL-ECRIS 2 project

The first plasma in the present 6.4 GHz JYFL-ECRIS was ignited eight years ago, on May 1991. The operating history of the source, without any exaggeration has been excellent. Only once its daily operation was interrupted due to a failure in the source body. A one week stop was caused by a cooling water leakage in the copper plasma chamber. Additionally a couple of turbo pump failures have taken place. Otherwise one annual maintenance has been enough to keep the source running. The log-meter of the rf transmitter presently shows over 34000 plasma-on hours. Although the source has been a good working horse, its beam intensities are no longer competitive in comparison with the most modern sources [1]. In the case of the medium charged ions, like Ar^{8+}, its capacity is smaller by a factor of ten.

Due to the requirements in ion beams with higher charges and heavier elements than the present JYFL-ECRIS can produce, JYFL decided in autumn 1998 to begin a design and construction project of a new ECR ion source, called as JYFL-ECRIS 2 (Fig.3). The project aims to build a source that is mainly based on the design of the 14 GHz AECR-U source at the LBNL. Some modifications made in the similar source under construction at the NSCL will be utilized here.

In the source modification most attention is being paid on both of the source ends, on the injection and extraction sections.

In the new source, in addition to normal gas ions, a wider assortment of solid ion beams is planned. The latter ones can be produced in the axially installed miniature oven and by the aid of the more advanced MIVOC technique [14]. There will be two means to make MIVOC beams. The other one is the ordinary way to use a separate MIVOC chamber.

A novelty will be an insert of compounds into a crucible of the miniature oven. In some cases this solution may enable better control in feeding of the compound vapor into the source.

To get a suitable vapor pressure into the plasma chamber the position of the oven can be lined axially and warming of the compound is possible, too.

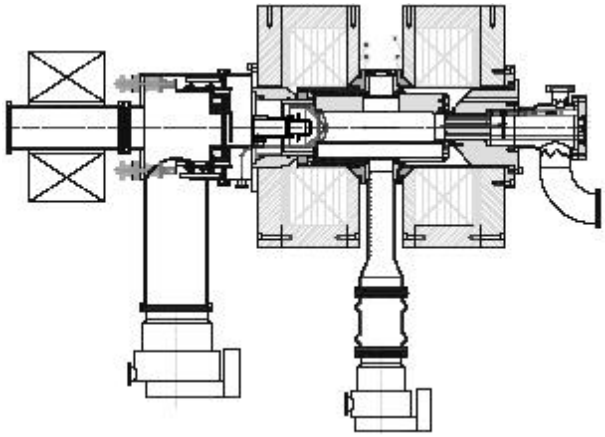

Fig.3. A scheme of the new 14 GHz JYFL-ECRIS 2.

This should give us more freedom in selecting the compounds, especially low vapor ones which don't work under the normal MIVOC technique. The compound or the solid piece in the crucible can be changed without breaking the vacuum.

Access to the extraction chamber is planned to be quick and easy: Beam-line components following the source, i.e. the glazer lens and the diagnostic box will be installed on a separate table. There they can be slid out in order to enter the extractor and the first plasma electrode. Presently the extractor of the source is under design. Entering into the injection chamber is planned to be as easy.

The new source will be installed horizontally in the basement of the ECRIS laboratory. It requires a new beam-line from the source to the injection line of the cyclotron, since the old vertically located JYFL-ECRIS will remain in operation. In the beginning the new source will operate as a single frequency source. It is planned to be operational during the year 2000.

6. Summary

Since 1996 the JYFL Accelerator Laboratory has worked under the Access to Large Scale Facilities (LSF) Program of the European Union. In 1998 altogether 48 different experiments on basic nuclear physics and applied physics were carried out. The JYFL cyclotron with its ECR ion source, delivered beams of 20 different isotopes. Especially a new RADEF facility for tests of electronics sets special requirements on the ion beams. To respond to these, so-called ion beam cocktails have been developed. In this connection the MIVOC technique has an important role. At the moment at least 20 different isotopes can be delivered as ion beams with the aid of the MIVOC.

Last year the JYFL-ECRIS was changed into a one stage source equipped with a negatively biased disc. As a result ion beams are more easily and quickly developed and an overall stability has still increased. As a highlight, a very stable beam of $^{48}Ca^{9+}$ was delivered continuously over a three weeks long beam time.

In future the present variety of ion beams, however, will not meet the experimentalists' increased demands. Essentially the capacity of the existing JYFL-ECRIS has already been utilized. For these reasons JYFL started a project to construct a new ECR ion source. It is designed in close collaboration with the LBNL and the NSCL. Two ECR ion sources in future will also give better conditions for development of new ion beams. Additionally tests of new constructional ideas are then possible.

Acknowledgements

The authors would like to thank Dr. C. Lyneis, LBNL, Dr. P. Miller and Mr. J. Ottarson, NSCL, and their group members for their valuable and continuous support on the JYFL-ECRIS 2 project.

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