Recent Developments in ECR Ion Source Technology at the MSU-NSCL

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Abstract

A summary of recent developments in ECRIS technology taking place at the Michigan State University National Superconducting Cyclotron Laboratory (MSU-NSCL) is presented in this paper. New techniques have been put into operation at the NSCL for the efficient production of ECRIS beams from solid materials. This includes the design and construction of a miniature, low-power ECR oven and a new technique for the efficient production of rare and costly isotopically enriched calcium beams from calcium oxide material. Also, further investigation and use of the direct ion sputter technique is reported. In addition, we report on (1) improved source performance through the implementation of new source hardware; (2) continuing developments in accelerator mass spectrometry (AMS) studies at the NSCL using ECR ion sources; and (3) collaborative research and work in ECRIS technology with other laboratories.

I. New Techniques for the Production of Ion Beams from Solid Materials

During the past year major time and effort has been devoted at the NSCL to increasing our capabilities for developing new and higher intensity ion beams from solid materials. The importance of having this capability is very apparent considering that at standard temperature and pressure (STP), of the eighty-three stable elements eleven of these exist as gases, four as liquids, and the remaining sixty-eight as solids. Clearly, having the capability to produce high quality, high intensity ion beams from the solid elements is vital to continuing a strong NSCL nuclear science program.

During the past year, two new methods have been implemented at the NSCL for producing ion beams from solid materials and with much success. The first method, the direct ion plasma sputtering technique [1], has proven to be a very simple and successful method for producing ion beams with the NSCL room temperature ECR (RTECR) ion source from a variety of solid elements. Basically, it consists of placing a negatively biased metal sample, introduced through one of the RTECR source's radial ports, just outside of the ECR plasma boundary (the sample is biased typically from -500V to -1200V). Positive ions on the edge of the inside plasma boundary (supplied by a support gas) are accelerated into the sample and sputter a small quantity of the metal sample into the plasma where it is ionized through the ECR process. It has been used, to date, at the NSCL to produce very stable and relatively intense beams of Ti, V, Cr, Mn, Fe, Co, Ni, Mo, Pd, Ag, Cd, Au and U. Small samples of isotopically enriched material, placed within a containing holder, have also been successfully sputtered. It should be noted that the direct ion sputter technique may prove useful for developing beams from additional solid elements not listed above. These will be attempted when the need arises.

As a second method for producing ion beams from solid materials, a miniature, low-power oven capable of reaching temperatures of 1400° C has been designed and built for use with the RTECR [2]. Fig. 1 shows a detailed cross-sectional view of the RTECR oven. Compared to the direct ion sputter technique, the oven is especially useful for producing beams from materials that do not sputter well and for very small isotopically enriched samples. The oven is an adaptation of the very successful micro-oven designed and used by the Grenoble group in their Caprice ECR ion source [3,4]. The small size of the RTECR oven allows it to be placed entirely within one of the RTECR source's radial ports which results in excellent coupling of solid vapors into the ECR plasma and thus minimal material usage rate. The oven and its orientation with respect to the source is shown in Fig. 2.

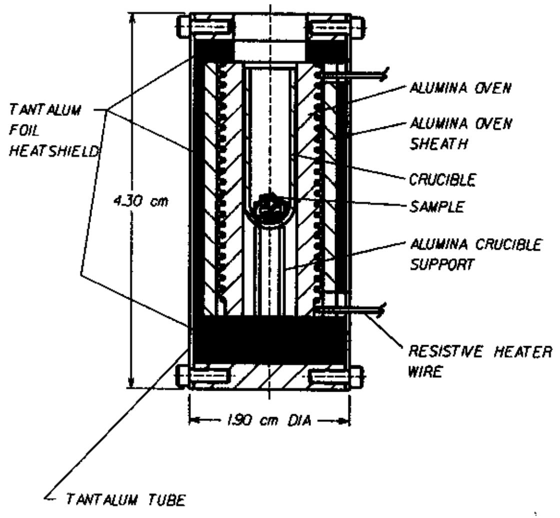

Fig. 1 Detailed cross-sectional view of the miniature RTECR oven.

To date, the oven has been used at the NSCL to produce beams from Be, B (using B_2O_3), Au, and isotopically enriched ^{48}Ca, ^{58}Fe, and ^{110}Pd. The oven design allows the use of very small sample sizes and very small material usage rates. For example, the costly ^{58}Fe sample was below 10mg in size and its material usage rate was approximately 0.03mg/hr. Most notably, the oven has been used to produce excellent ^{48}Ca beams employing a new technique [2]. The technique involves the on-line reduction, by zirconium, of isotopically enriched ^{48}CaO. This technique has resulted in very stable and longterm (run times of over one week) ^{48}Ca beams with intensities as high as 25pnA being extracted from the K1200 cyclotron (70MeV/A using $^{48}Ca^{12+}$) with a material usage rate of below 0.1mg/hr. This technique is especially useful considering the high cost of isotopically enriched ^{48}Ca and the difficulties associated with handling small quantities of calcium metal (rapid oxidation).

A similar oven has been built and successfully tested for solid beam production with the NSCL superconducting ECR (SCECR) ion source. Since the SCECR has no radial ports, the oven has been designed to be mounted axially in the injection region of the source as shown in Fig. 3. Since the ion source is "vertical" in its spatial orientation, the design of the oven demands that samples which liquify before reaching required vapor pressure temperatures, such as Pb and Au, be adequately contained in a small oven crucible without spilling down into the ECR plasma chamber and still allow vapors from the solid to freely enter the plasma. Our "inverted" SCECR oven and square shaped crucible designs, shown in Fig. 4, have successfully met these demands.

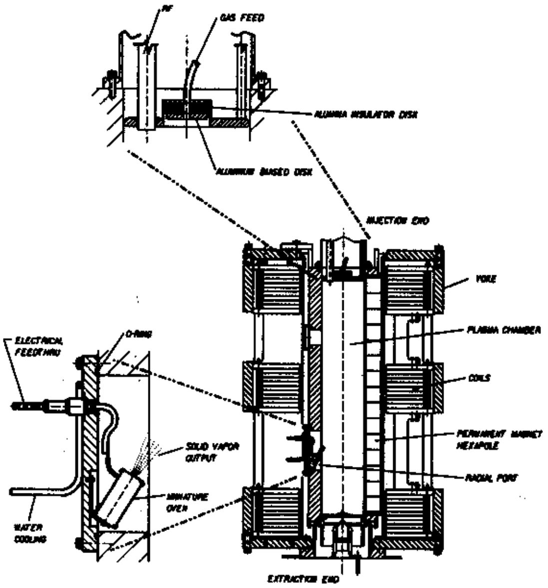

Fig. 2 Cross-sectional view of the MSU-NSCL RTECR ion source showing the miniature oven mounted within one of the source's radial ports. Figure also shows aluminum biased disk which replaces original first stage.

Presently, the direct ion sputter technique is also being investigated for use with the SCECR. One option is to have the sputter samples introduced axially in the injection region of the source. We have observed that finding the correct location of the sputter sample relative to the plasma in this axial orientation is more of a challenge as compared to the RTECR radially introduced sputter samples. A second option is to simulate a radially introduced sample by running an insulated (using Al_2O_3 tubing) wire down the side of the plasma chamber then terminating the wire with a 90° bend to which a sputter sample is attached. The insulated wire is oriented to minimize plasma interaction. This second option appears to be more promising and has already been used to develop Ag and

Au beams. Presently, we are still perfecting the sputter technique for use with the SCECR.

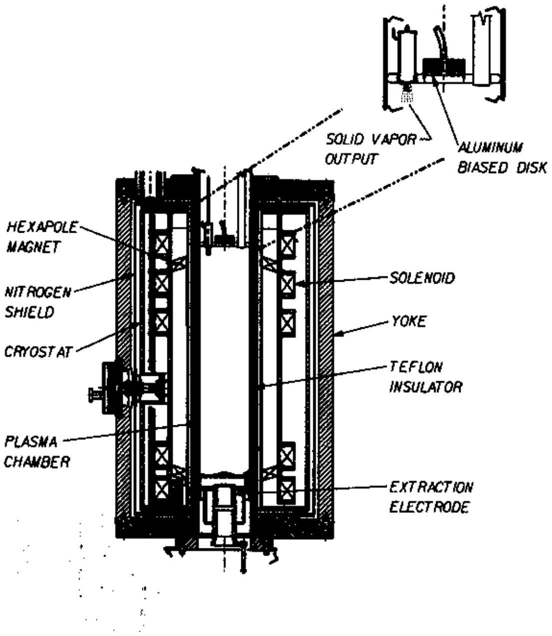

Fig. 3 Cross-sectional view of the MSU-NSCL SCECR ion source showing the "inverted" oven mounted axially in the injection region of the source. Figure also shows aluminum biased disk which replaces original first stage.

II. Improvements in Source Performance Through the Implementation of New Hardware

In an effort to improve performance, new hardware has been installed in the RTECR and SCECR ion sources during the past year. It has been demonstrated [5] that an enhancement of ECR ion source performance can be achieved through the application of plasma chamber aluminum coatings. At the NSCL we have designed evaporation hardware which has allowed us to coat (online, without removing the chamber from the ion source) both the RTECR and SCECR plasma chambers with a very thin layer of aluminum. Some evidence of improved source performance has resulted from these coatings. In addition, the copper extraction orifice of the SCECR ion source has been replaced with an aluminum one in an effort to further take advantage of this technique.

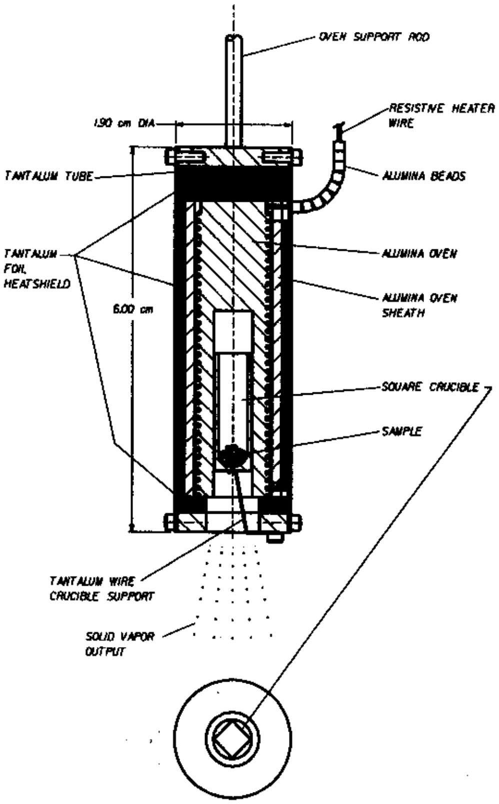

Fig. 4 Detailed cross-sectional view of the miniature "inverted" SCECR oven.

Also during the past year, both on the RTECR and SCECR ion sources, first stage hardware has been removed and entirely replaced with an aluminum biased disk. This is shown in Figs. 2 and 3. Since the placement of the disk and removal of the first stage hardware, performance of both sources appears to be as good, and better, as compared to the past. In addition, this modification allows for simpler source operation and is more compatible with the SCECR oven hardware described above.

III. Continuing AMS Program at the NSCL Using ECR Ion Sources

We are continuing to develop an accelerator mass spectrometry (AMS) program using ECR ion sources at the NSCL [6,7] in collaboration with W. Kutschera *et al.* from the University of Vienna, Austria. The SCECR is being used, along with the K1200 cyclotron and A1200 separator, in a series of measurements which are currently determining and comparing the amount of ^{81}Kr in present-day atmospheric krypton (estimated to be approximately one part in 10^{13}) and ^{81}Kr in samples of pre-nuclear testing (*pnt*) atmospheric krypton. This is very exciting research as ^{81}Kr is a cosmogenically produced radionuclide (the recent tests comparing present day and *pnt* samples will determine if any is anthropogenically produced), having a half-life of 210,000 years, which has the potential of developing into a reliable absolute chronometer for dating old ice in polar ice caps and ground water in the age range from 50,000 to 1,000,000 years. In order to meet the demanding constraints required to perform these AMS measurement successfully, a special gas handling system has been designed and built at the University of Vienna for use with the SCECR. The system includes a cryogenic trap for eliminating unwanted trace contaminants (specifically ^{81}Br). In addition, the system allows for the rapid change of multiple samples via computer control. The most recent AMS measurement at the NSCL was carried out in December 1996 and data collected during that time period is presently being analyzed.

IV. Collaborative Research and Work in ECRIS Technology with Other Laboratories

In the recent past, collaborative ECR ion source research has been carried out between the NSCL and a number of other laboratories.

The SCECR has been used to further investigate frequency and magnetic field scaling in ECR ion sources with our collaborators from INFN Catania, Italy [8]. Specifically the High-B mode of operation [9], where a much higher axial and radial magnetic field than is required for electron cyclotron resonance is used and which has resulted in the impressive performance of the SCECR and other ECR ion sources [10,11], has been investigated in greater detail. The SCECR was operated at a microwave frequency of 2.45GHz (the source typically operates at 6.4GHz) in an effort to determine the degree to which the High-B mode can be extended. The conclusion of these most recent tests indicates that improvements can be achieved with a radial magnetic field four to five times higher than is needed for resonance. In addition, increasing the source microwave frequency is beneficial provided that a high enough magnetic confinement field can be maintained. These tests indicate that even higher performance can be expected from the 6.4GHz SCECR if the field of the source's hexapole magnet can be increased. Presently, the hexapole magnet can only achieve one-third of its design field before quenching. Plans to rebuild the hexapole are underway and the above tests indicate that we can expect much improved performance from the higher field hexapole. Due to the success of the High-B mode, plans are presently underway to upgrade the NSCL RTECR to match the high mirror and hexapole fields of the SCECR, as was done with the Texas A&M ECR ion source [10,11].

During the past year, the NSCL has also been very actively involved with other laboratories in the development of ECRIS beams from solid materials. Our miniature oven technology, described above, has been introduced to and adopted by ion source groups at Argonne ATLAS, the Texas A&M Cyclotron Institute, and the University of Jyväskylä Accelerator Laboratory.

We are currently developing a working collaboration with The Institute of Nuclear Science (ATOMKI), Debrecen, Hungary. It is the goal of this ATOMKI/NSCL collaboration to bring about a mutual exchange of ideas and technology from which both laboratories will benefit. In the very near future, we hope to introduce and help put into operation NSCL oven and sputter technology for the production of beams from solid materials in the new ATOMKI ECR ion source [12]. We also hope to study and better understand ECRIS plasma phenomena, particularly related to the direct ion sputter technique, using the ATOMKI developed TrapCAD code [13]. The TrapCAD code will also be used to optimize the design of the NSCL upgraded RTECR ion source.

Acknowledgements

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