LBL-37311
UC-413

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the Twelfth International Workshop on Electron Cyclotron Resonance Ion Sources, Tokyo, Japan, April 25–27, 1995, and to be published in the Proceedings

Concept for a Third Generation ECR Source at LBL

C.M. Lyneis and Z.Q. Xie

April 1995

REFERENCE COPY
Does Not
Circulate
Bldg. 50 Library.
LBL-37311
Copy 1

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Lawrence Berkeley Laboratory is an equal opportunity employer.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL - 37311
UC 413

CONCEPT FOR A THIRD GENERATION ECR SOURCE AT LBL

C.M. Lyneis and Z.Q. Xie

Nuclear Science Division, Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720, USA

April 1995

This work was supported by the Director, Office of Energy Research Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

CONCEPT FOR A THIRD GENERATION ECR SOURCE AT LBL

C. M. Lyneis and Z. Q. Xie

Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, California, 94720, USA

Abstract

Although the Advanced Electron Cyclotron Resonance ion source has produced record high charge state beams and is now in operation with the 88-Inch Cyclotron, development of a third generation ECR source could provide major new research opportunities at with the 88-Inch Cyclotron. Higher intensities for particles with mass greater than 150 and energies above the Coulomb barrier would improve experiments using deep inelastic reactions to produce neutron rich compound nuclei that can be studied with the Gammasphere detector or its successor. Very high intensities (several particle μA from the cyclotron) for masses between 30 to 65 would greatly benefit the heavy element research. On the basis of on progress in ECR source development, a third generation ECR source with multiple-frequency microwave drives, enhanced magnetic mirror ratios and high secondary emission walls for additional cold electrons could extend the performance of the cyclotron into the areas described above and serve as a tool for ECR study.

Introduction

The development of a third Generation ECR source at LBL would provide both new scientific opportunities in nuclear science research at the 88-Inch Cyclotron and the opportunity to advance ECR source technology. While the gains in ECR ion source technology have come at a slower rate in the last few years, recent results with two-frequency heating,[1,2] high mirror ratios [3] and enhanced supplies of cold electrons [4] indicate that further advances are possible. To incorporate these ideas into a new Multiple Frequency ECR source (MF-ECR) will mean an increase in complexity over existing designs, but improving ion source performance continues to be a cost effective method to better heavy-ion accelerator performance. The performance of the 88-Inch Cyclotron has increased to a remarkable extent, first when the LBL ECR began operation with the cyclotron in 1985 and again over the last few years as the Advanced ECR (AECR) has reached its full potential. Every element from hydrogen to copper has now been accelerated through the 88-Inch Cyclotron and used for experiments. Many other elements as well as rare isotopes are also accelerated.

For nuclear structure experiments, the typical beam requirements are 4 to 6 MeV/nucleon at 1 to 2 particle nA (6 to 12×10^9 pps). With the present AECR this means that elements up to mass 150 can be used for these experiments. One of the goals of the MF-ECR would be to increase the usable mass range up to uranium. Recent beams produced with the AECR driven by two frequencies [1] have resulted in the acceleration of Bi^{45+} to 6.3 MeV/nucleon and U^{53+} to 7.0 MeV/nucleon. Although the extracted

currents from the cyclotron of 6.9 $\times 10^7$ and 9.4. $\times 10^5$ particles per second, respectively, were too small for most nuclear physics experiments, they indicate that very high charge state ions can be produced by ECR sources and accelerated in a cyclotron. Another research area is the study of the nuclear and chemical properties of heavy elements. A new gas filled spectrometer is being designed to provide new research opportunities in this area. To achieve the optimum production of these low cross section reactions it will require about 2 particle μA beams at about 7 MeV/nucleon from the cyclotron for elements with masses between 30 and 65. Tests with gaseous elements such as argon in the AECR have demonstrated it is possible to inject and accelerate the high intensity beams needed. One of the goals of the Multiple Frequency ECR would be to produce high intensity metal ion beams necessary for these low cross section experiments.

ECR Issues

The strategy to maximize the performance of the MF-ECR source is to combine three different ideas. These are multiple frequency heating, high mirror ratio axial and radial magnetic fields and techniques to provide a sufficient supply of cold electrons to the plasma. The recent results with two-frequency heating on the AECR demonstrated significant gains for the production of heavy, high charge state ions. In the MF-ECR this will be extended so that three or more frequencies can be used simultaneously.

There is much experimental evidence that higher magnetic field ECR sources have higher performance. The most dramatic example is the high B mode performance of the MSU SC-ECR which operates at 6.4 GHz.[3] When this source was operated at very high axial mirror ratios (6 at injection and 3.5 at extraction) and at relatively strong radial magnetic field ($B_r \sim .45$ T at the plasma wall) its performance was comparable to the best 14 GHz operation.[5] Many other examples such as the higher performance of the CAPRICE sources as the axial and radial magnetic fields were increased [6] indicate that magnetic field strength plays a crucial role in the production of high charge states. While the gains originally credited to frequency scaling may have been due to the increase in magnetic field strength, a key question remains to be answered. That is, if the high mirror ratio fields used in the SC-ECR are scaled to higher frequency can further progress be made? To answer this question requires a high field superconducting ECR source that can exceed the limitations on field strength imposed by the use of copper coils and permanent magnets. The MF-ECR would be able to explore this question as will the SERSE ECR source now under construction. [7]

The third crucial ingredient to making very high charge states is to provide sufficient cold electrons to the plasma. There are several techniques to do this including external electron gun,[8] a first stage ECR source,[9] a biased disk [10] or an appropriate surface on the plasma chamber wall. On the basis of on our tests with the AECR source the most effective is to use a chamber wall with either a coating of aluminum or constructed from aluminum. Aluminum forms a tough oxide layer that has a very high secondary emission coefficient. This provides a constant source of cold electrons that improves plasma stability, reduces the plasma potential [4] and allows operation at lower neutral densities. Since aluminum has excellent thermal conductivity we plan to build the inner wall of the source with aluminum.

B on axis	
$B_{injection}$	≤ 4.5 T
$B_{extraction}$	≤ 3.2 T
B_{min}	.3 T (variable)
B_r at wall	≤ 2.5 T
Plasma chamber dia.	160 mm
Main coil separation	500 mm

Table I. MF- ECR Source Parameters

Design Considerations

Current design efforts are focused on developing the optimum magnetic geometry for the MF-ECR. Figure 1 illustrates a preliminaryconceptual design with 3 superconducting solenoid coils to provide the axial magnetic field and a superconducting sextupole coil for radial magnetic field confinement. The parameters for the magnetic elements and other parameters are listed in Table I. The iron yoke is designed to provide a return path for the flux and to reduce the stray field outside the source. In order to achieve the high mirror ratios, the center solenoid coil

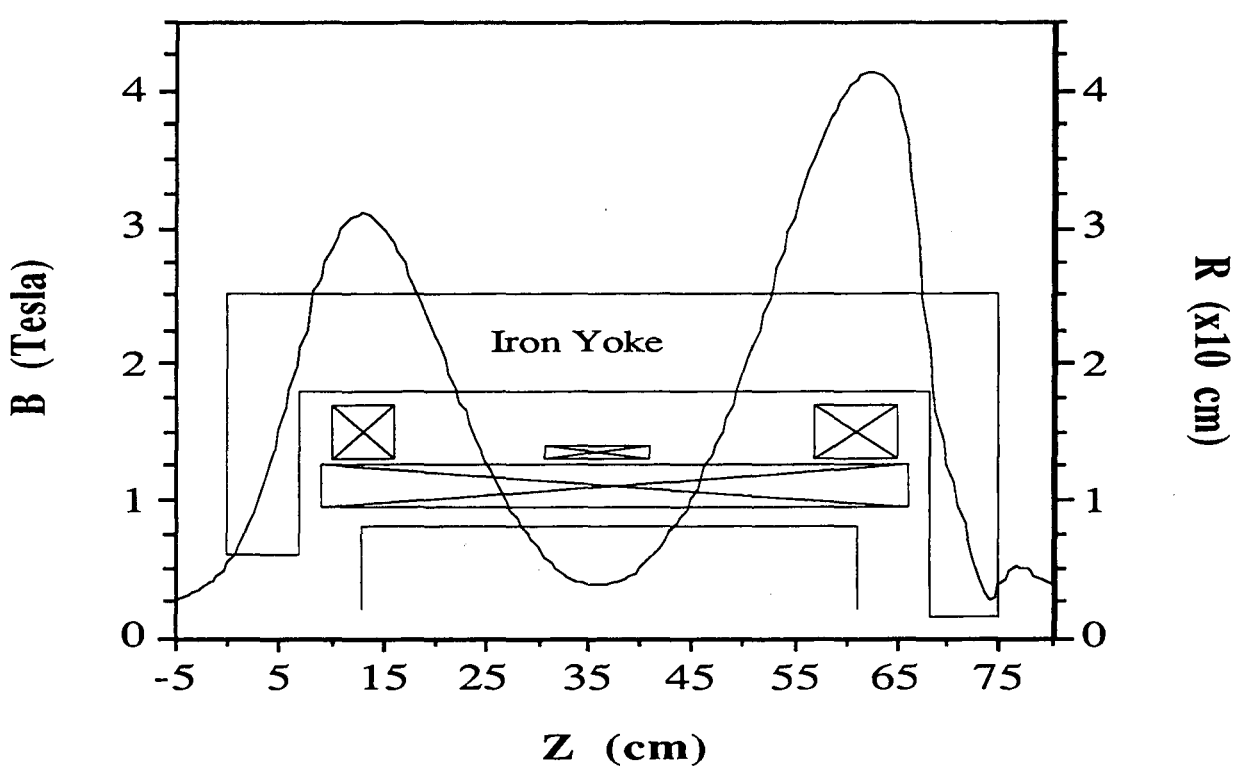

Fig. 1. A schematic drawing showing the main magnetic elements of the MF-ECR source. The axial magnetic field is show superimposed on the source drawing. The coils at each end provide the strong mirror fields and the center coil produces an opposing field to provide the large mirror ratio.

would be operated to reduce the axial field at the center of the mirror. Calculations of the magnetic fields have been done with the three dimensional magnet code TOSCA. One of the limits to using very high axial field gradients is that the axial field generates large B_r components at the chamber wall. The radial components of the axial field combine with the radial components of the sextupole fields and at angles where the fields oppose each other there is a significant reduction the B_{mod}. This produces a weak point in the B_{mod} at the wall and may limit the usable axial field gradients and favor longer mirror configurations.

A key design goal of the MF-ECR is to provide a magnetic field geometry so that closed ECR zones can be simultaneously produced at 10, 14 and 18 GHz as illustrated in Fig. 2. The choice of these frequencies is based on the commercial availability of transmitters but other frequencies higher or lower could be used. In order to support 3 well-separated ECR zones requires a large mirror ratio in the axial field. This is consistent with the idea of using high mirror ratio axial and radial fields.

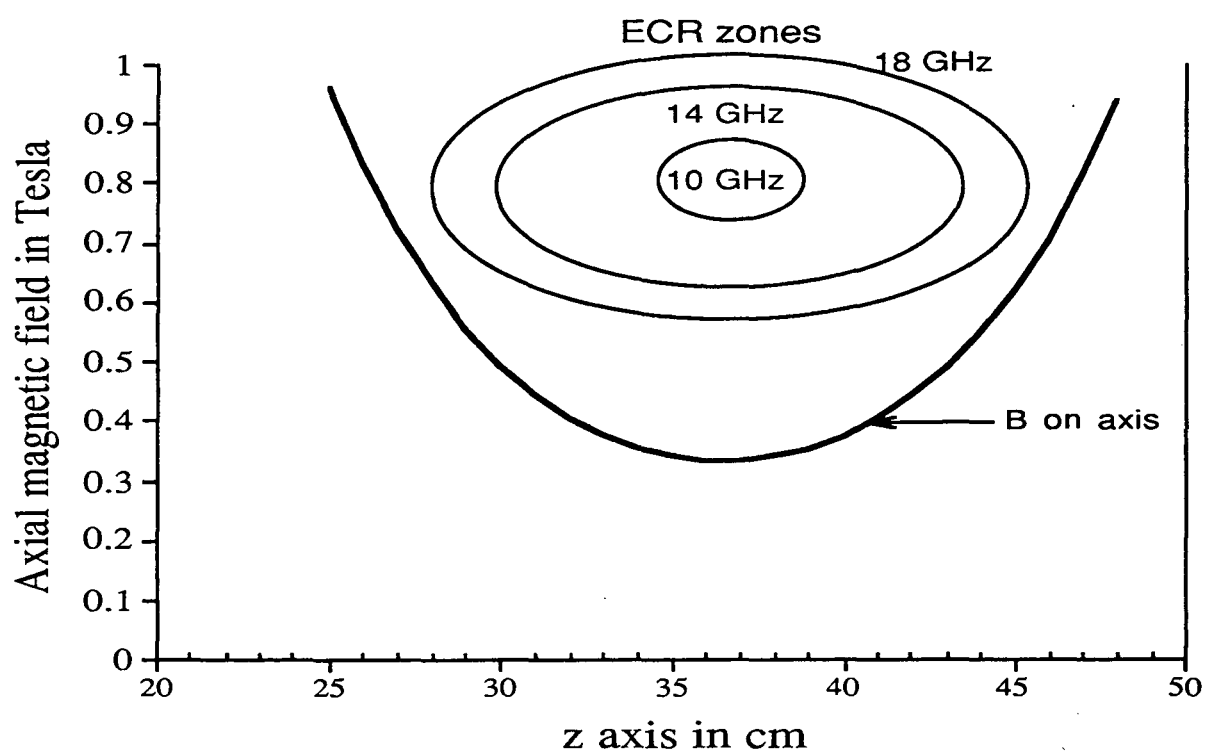

Fig. 2 An illustration of the nested ECR zones that can be created in the MF-ECR source.

More detailed studies of the limits imposed by the forces between the coils, localized field strengths and critical current densities within the superconductors will be done over the next several months.

Acknowledgment

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the U.S. Department of Energy under Contract DE AC03-76SF00098.

References

[1] Z. Q. Xie and C. M. Lyneis, (to be published in Rev. Sci. Instrum.)
[2] Z. Q. Xie and C. M. Lyneis, in Proceedings of this Workshop.
[3] T. A. Antaya and S. Gammino, Rev. Sci. Instrum. **65**, (1994) 1723.
[4] Z. Q. Xie and C. M. Lyneis, Rev. Sci. Instrum. **65**, (1994) 2947.
[5] G. Melin, in Proceedings of 6th Int'l Symposium on EBIS, Stockholm, 1994.
[6] B. Jaquot, R. Geller, in Proceedings of the International Conference on ECR Ion Sources and their applications, East Lansing, NSCL Report #MSUCP-47, 1987, p. 254.
[7] G. Ciavola, S. Gammino, P. Briand, F. Bourg, G. Melin, R. Lagnier, P. Seyfert, L. Losasso, R. Penco, in Proceedings of this Workshop.
[8] Z. Q. Xie, C. M. Lyneis, R. S. Lam, and S. A. Lundgren, Rev. Sci. Instrum. **62** (1991) 775.
[9] R. Geller, IEEE Trans. NS-26, No. **2** (1979) 2120
[10] G. Melin et al, in Proceedings of the 10th International Workshop on ECR Ion Sources, Oak Ridge, ORNL CONF-9011136, 1990, p. 1.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL AND ELECTRONIC
INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720