EXPERIMENTAL STUDY OF AN ECR ION SOURCE FOR ACCELERATOR MASS SPECTROMETRY*

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This study of an electron cyclotron resonance (ECR) ion source was undertaken to generate carbon ions for Accelerator Mass Spectrometry (AMS). Production of positive and negative carbon ions were studied. The simple and inexpensive source was also tested for He^{+1} and He^{+2} production for injection of low charge state light ions from directly under the superconducting cyclotrons. AMS accurately measures the ratio of ^{14}C to ^{12}C in a given sample at concentrations as low as 10^{-15} for dating of archeological materials. In a typical AMS system, a beam of negative carbon ions is produced from graphite by a cesium sputter ion source. The C- beam is used in order to eliminate nitrogen contamination, which does not form a stable ^{14}N- ion. The C- beam is then accelerated, stripped to a high positive charge state to remove molecular isobars and then individual ions are counted to determine the ratio. The graphite is produced by burning the sample, and processing the CO and CO_2 into solid graphite. Graphite samples have the disadvantage of being costly and time consuming to prepare. Direct use of CO_2 by a gas fed ion source would greatly reduce the cost and increase the number of samples processed. The gas fed ion source can directly generate the C-, or C+ can be converted to C- in a cesium charge exchange canal after extraction from the ion source. This would allow application of AMS to biomedical and environmental research where ^{14}C is used as a tracer with concentrations greater than the naturally occurring level of 10^{-12} [1, 2].

Design

The requirements for a gas fed ion source suitable for AMS measurements are:

- Production of >1 mA of C- or >100 mA of C+ .
- Conversion of CO_2 to C ions with greater than 1 % efficiency.
- Memory of previous CO_2 sample less than 1 minute.
- Low emittance beam suitable for injection into a tandem accelerator.
- Simple and inexpensive, turn-key source for multiple AMS systems.

High frequency ECR ion sources used at the NSCL and elsewhere generate higher positive C+ currents than required for AMS, but are too expensive and as designed their internal complexity would not meet the conversion and memory requirements. To meet these requirements, this research investigated an ECR ion source using an inexpensive 2.45 GHz, 600 W magnetron similar to those used in microwave ovens. The source is gas fed with a low operating pressure. The low gas flow rate should allow short memory of each CO_2 sample and high conversion efficiency. Also, an all stainless steel cylindrical plasma chamber at high temperature with minimal internal surface area will further reduce contamination. The magnetic bottle consists of solenoids for axial confinement and a quadrupole field for magnetohydrodynamic (MHD) stability.

Figure 1 shows a schematic of the ECR ion source built and tested for this study. Figure 2 shows the experimental setup with bend magnet to determine ion species and charge state. The cavity dimensions were chosen for operation in the TE_{111} mode with a tuning stub to operate at 2.45 GHz before and after igniting the plasma. A coupling loop is used to excite the mode, and a window is on the opposite side of the cavity for observation.

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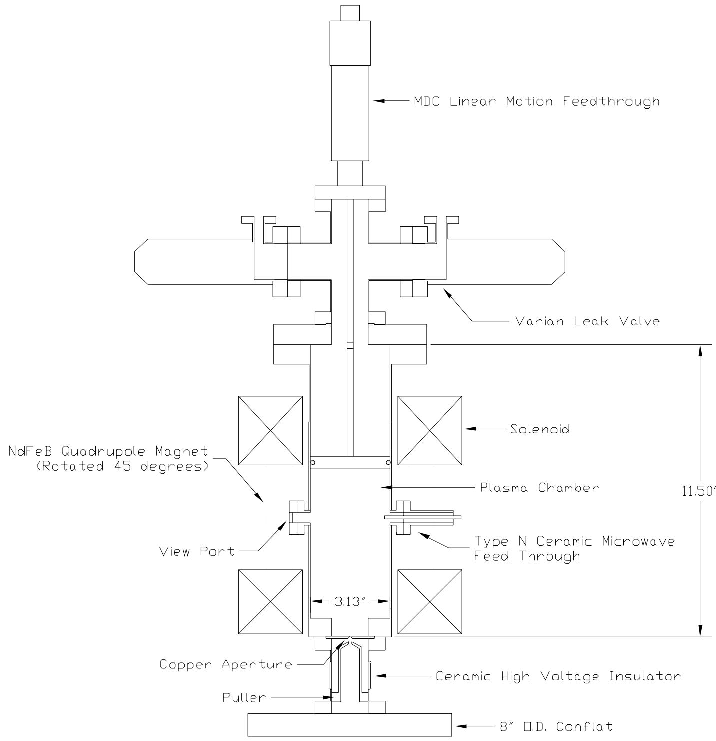

Figure 1. Schematic of ECR Ion Source

The mirror magnetic field is generated by two independent solenoids. The maximum mirror ratio is 1.6 with a minimum field for resonance of 0.875 kG. The low mirror ratio decreases the maximum magnetic field required and the plasma confinement, but it should be adequate for negative ion and low charge state ion production. To reach higher density plasmas a NdFeB permanent magnet quadrupole field was added. The field at the magnet face was 3.6 kG.

The extraction aperture is 4 mm in diameter with a 5 mm gap. An accelerating voltage up to 10 kV has been used although most tests have been at 5 kV. There are Faraday cups before and after the analyzing magnet. The vacuum system consists of a 500 liter/second turbo, two leak valves to mix gases and all metal/ceramic construction. The total cost to reproduce this ECR ion source, including all vacuum equipment and power supplies, is less than $30,000.

Experimental Results

The vacuum system was pumped down to a base pressure in the mid 10^{-8} torr range. Up to two gases were leaked into the system at a time with He, Ar and CO_2 available. Maximum input power was limited to about 100 W due to the vacuum microwave feedthough. The highest currents reached are listed in Table 1. These currents were reached with a beamline pressure of about $3x10^{-6}$ torr, which corresponds to a 0.4 % conversion efficiency of CO_2 to C+. After extended operation with CO_2 and without heating the chamber walls, the CO_2 was switched to Ar. The C+ current quickly dropped to 0.3 mA and then to 0.03 mA in about an hour. Further memory tests with short CO_2 runs followed by Ar with the chamber at high temperature have not yet been performed. The C+ current is about a factor of five lower than that required for AMS, but substantial improvements are possible by raising the mirror ratio and increasing the plasma volume. This will also increase the conversion efficiency to useable levels. The memory will improve once the vacuum chamber is maintained at high temperature. These changes should also increase the C- current, but reaching the AMS requirements for negative ion production inside the ECR ion source is less likely.

Table 1. Highest Currents Obtained From ECR Ion Source

C-	0.01-0.02 mA
C+	18 mA
He^{+1}	55 mA
He^{+2}	3 mA

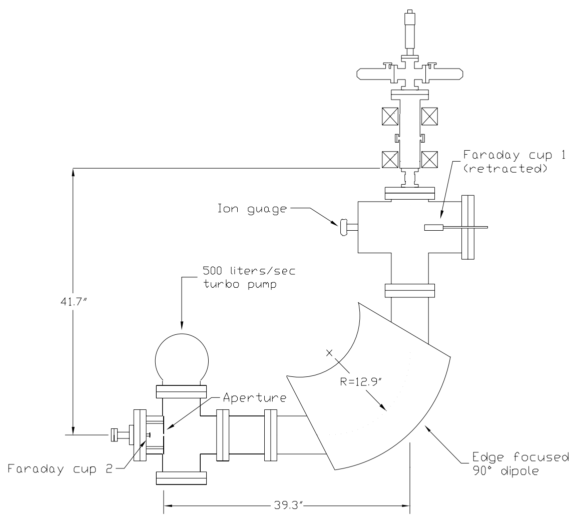

Figure 2. ECR Ion Source Experimental Setup

References

1. J.C. Davis, “AMS beyond 2000”, Nuclear Instruments and Methods in Physics Research, B 92, p. 1 (1994)

2. W.H. Scharf, “Biomedical Particle Accelerators”, AIP Press, Woodbury NY, p. 634, (1994)