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Hudson et al.

[11] **3,898,496**

[45] **Aug. 5, 1975**

[54] **MEANS FOR OBTAINING A METAL ION BEAM FROM A HEAVY-ION CYCLOTRON SOURCE**

[75] Inventors: **Ed D. Hudson**, Knoxville; **Merrit L. Mallory**, Oak Ridge, both of Tenn.

[73] Assignee: **The United States of America as represented by the United States Energy Research and Development Administration**, Washington, D.C.

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[52] **U.S. Cl.** **313/62;** 313/218; 313/224; 313/362

[51] **Int. Cl.**[2] **H01J 61/06;** H01J 61/16; H05H 13/00

[58] **Field of Search** 313/62, 359, 330, 218, 313/224, 362; 328/234; 315/111.8

[56] **References Cited**

UNITED STATES PATENTS

3,226,598	12/1965	Van Nimwegen	328/234 X
3,393,339	7/1968	Hill et al.	313/359 X
3,566,185	2/1971	Gavin	313/230 X
3,624,527	11/1971	Hudson	313/234
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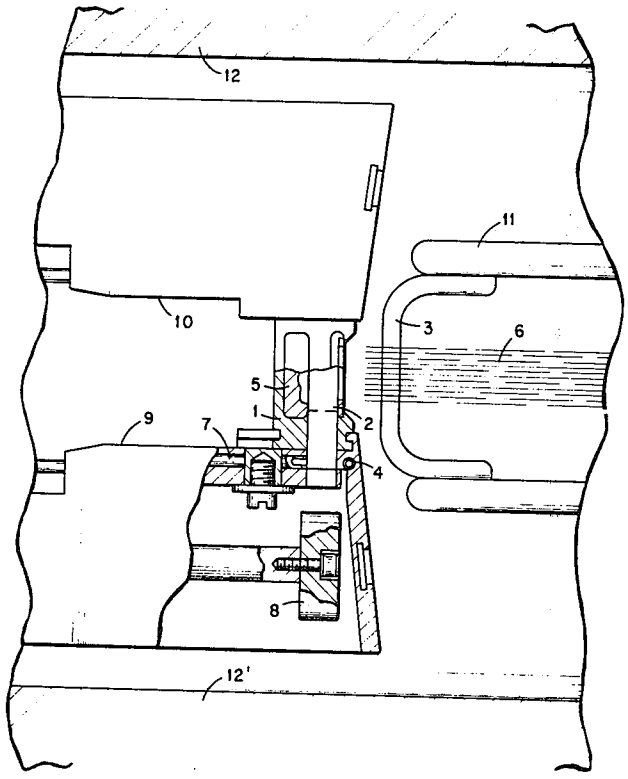
Primary Examiner—Palmer C. Demeo

Attorney, Agent, or Firm—Dean E. Carlson; David S. Zachry; Louis M. Deckelmann

[57] **ABSTRACT**

A simple method for producing a high intensity metal ion beam from a high-powered Penning-type ion source in a cyclotron is provided. A small amount of an inert support gas maintains the usual plasma arc, except it is necessary for the support gas to have a heavy mass, e.g., xenon or krypton as opposed to neon. A plate, fabricated from the metal (or anything that can be sputtered) to be ionized, is mounted on the back wall of the ion source arc chamber and is bombarded by returning energetic low-charged gas ions that failed to successfully cross the initial rf accelerating gap between the ion source and rf accelerating slit. Some of the atoms that are dislodged from the plate by the returning gas ions become ionized in the plasma arc column and are extracted as a useful beam of heavy ions.

6 Claims, 3 Drawing Figures



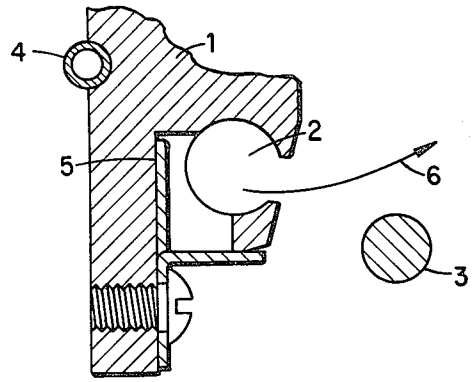


Fig. 1

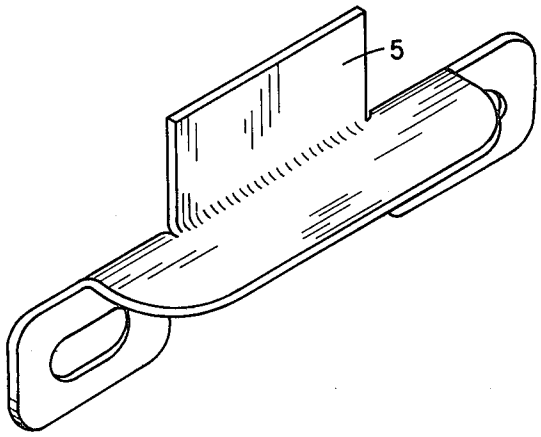


Fig. 2

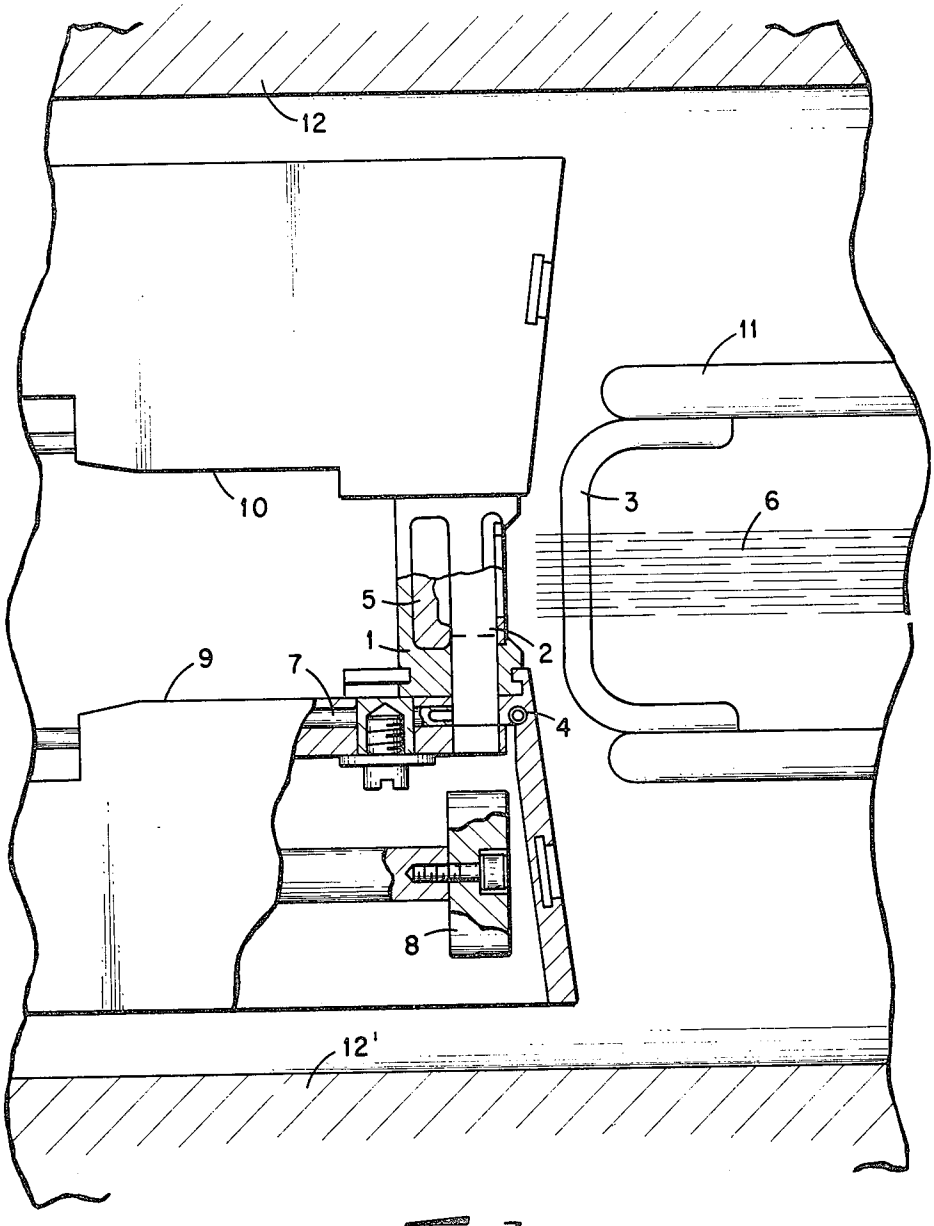


Fig. 3

MEANS FOR OBTAINING A METAL ION BEAM FROM A HEAVY-ION CYCLOTRON SOURCE

This invention was made in the course of, or under, a contract with the U.S. Atomic Energy Commission.

BACKGROUND OF THE INVENTION

The present invention was conceived for use with isochronous cyclotrons such as the Oak Ridge Isochronous Cyclotron (ORIC) now in experimental use at the Oak Ridge National Laboratory. Details of the structure and operation of the ORIC system may be obtained from *Nuclear Instruments and Methods*, 18, 19, Nov. 1962, pp. 46–61, 159–176, 303–308, and 601–605; from U.S. Pat. No. 3,624,527 issued Nov. 30, 1971; and from the Oak Ridge National Laboratory Electronuclear Division Annual Progress Report No. ORNL–3630, dated June 1964, pp. 38–62.

The ORIC system is provided with a magnetic field, an internal ion source provided with an arc chamber, a variable radio-frequency (rf) system including an rf accelerating slit for withdrawing ions from the ion source arc chamber, the rf system effecting the acceleration of the withdrawn ions through the cyclotron as guided by the magnetic field, and an ion beam extraction system for extracting a desired separated ion beam from the cyclotron such as described in the above publications.

Recently in the field of heavy-ion research, there have been efforts directed to the production of beams of metal ions. Such efforts are due in part to recent discoveries that heavy-ion beams can be used to probe the properties of matter and that damage to reactor structural materials can be simulated by bombarding the materials with ions of the same atomic species, e.g., with metal ions. There has been some limited success to date in the production of beams of metal ions, but the methods employed have not been fully satisfactory because the actual extraction process that is occurring has not been understood. Some of these prior methods are set forth in the following publications:

1. B. F. Gavin, Nuclear Instruments and Methods 64(1968)73.

2. A. S. Pasyuk and Yu P. Tretyakov, in Proceedings of the Second International Conference on Ion Sources (SGAE, Vienna, 1972) 512.

3. E. J. Jones, IEEE Trans. Nuclear Science NS–19, No. 2 (1971)101.

It should be noted that the above prior art methods do not involve the concept of producing heavy metal ion beams utilizing a cyclotron. It has been determined that cyclotrons can in fact be utilized to produce such ion beams of a desired metal in a unique manner to be described hereinbelow.

SUMMARY OF THE INVENTION

It is the object of the present invention to modify a cyclotron in such a manner as to produce a desired heavy metal ion beam therefrom.

The above object has been accomplished in the present invention in the following manner. A small amount of an inert support gas maintains the usual plasma arc in the cyclotron ion source, except that it is necessary for the support gas to have a heavy mass, e.g. xenon or krypton as opposed to neon. A plate, fabricated from the metal or compound to be ionized, is mounted on the back wall of the ion source arc chamber and is bombarded by returning energetic lowcharged gas ions

that failed to successfully cross the initial rf accelerating gap between the ion source and accelerating slit. Some of the metal atoms that are dislodged by the returning gas ions become ionized in the arc plasma column and are extracted as a useful beam of metal ions.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a sectional view of only the ion source portion of a cyclotron which involves the present invention, and

FIG. 2 is an isometric view of the metal plate utilized in the cyclotron ion source of FIG. 1 for producing a metal ion beam;

FIG. 3 is a more detailed side sectional view of the ion source of FIG. 1 and its relationship to some other portions of the cyclotron.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A conventional cyclotron ion source 1 includes an arc chamber 2, an accelerating slit 3 and a water cooling line 4. The ion source 1 is modified by providing a plate 5, shown in more detail in FIG. 2 and fabricated from the metal to be ionized, which is mounted on the back wall of the ion source arc chamber 2.

With reference to FIG. 3, a more detailed view of the ion source of FIG. 1 and its relation to some of the components of a conventional cyclotron is illustrated. It should be noted that the ion source 1 of FIG. 3 is rotated 90° from its position as shown in FIG. 1. As can be seen in FIG. 3, the ion source 1 includes other conventional components such as a cathode holder 9 provided with a gas feed tube 7 for feeding a support gas to the ion source and a rotating cathode 8, and an anode holder 10 for supporting an anode, not shown, such that an arc discharge can be initiated between the cathode and anode through the ion source chamber 2. The metal plate 5 of the desired metal is shown partially eroded away in FIG. 3 which is caused by the backstreaming ions that fail to cross the accelerating gap between the ion source and the accelerating electrode 3 in a manner to be described hereinbelow. The accelerating electrode 3 is supported by the conventional dees 11 of the cyclotron. The complete ion source is supported by means, not shown, between the magnetic yokes 12 and 12′ of the cyclotron in a conventional manner. The ion beam extraction system for the ORIC is described in the above-mentioned publications and also in the copending application of E. D. Hudson et al., Ser. No. 444,458, filed Feb. 21, 1974, to which reference is made. The remaining components of the conventional cyclotron are not shown in FIG. 3 since such a showing is not necessary for an understanding of the present invention.

The following discussion will provide an understanding which led to the present inventive concept in producing a desired heavy metal ion beam from a cyclotron when the ion source thereof has been modified in accordance with the drawings as discussed above.

During an experiment on the Oak Ridge Isochronous Cyclotron (ORIC) requiring the acceleration of $^{130}Xe^{12+}$, a large intensity beam of about ½ eμA was detected and identified as $^{65}Cu^{6+}$. Substitution of neon gas in ORIC's cold cathode Penning discharge ion source resulted in a large reduction of the copper beam current (by a factor of 20) and led to the conclusion that a mass-associated process was involved. From previous

examination of the ion source (made of copper), it had been noted that the material directly behind the ion source slit in the plasma chamber was eroding. Replacement of this material with a piece of nickel, as illustrated in the drawings, resulted in a dramatic reduction of the copper beam. Adjusting the cyclotron operating parameters for nickel showed the presence of a large nickel beam.

Further investigation into the phenomenon showed that the dependence of beam current upon the dee voltage of the cyclotron is greater with the metal ions than with support gas beams of comparable mass. Orbit calculations of low charge-to-mass ions starting at various rf phases were then carried out. In the calculations, low charge xenon ions extracted from the ion source failed to successfully cross a 1-cm rf accelerating gap before reversal of the voltage when the cyclotron frequency was set to accelerate $^{56}Fe^{6+}$ ions on the third harmonic. The explanation, then, is that some gas ions will undergo a direction reversal and be accelerated back into the ion source to bombard the observed erosion area. The calculations further indicated that $^{132}Xe^{1+}$ ions for all extracting phases never cross the accelerating gap but are accelerated back into the ion source arc chamber. At the peak rf voltage (80 kv), where the maximum number of metal ions are extracted from the ion source, the $^{132}Xe^{1+}$ ions, having reversed direction, reach the back wall of the ion source chamber with an energy of 37 keV. Thus, some of the metal atoms that are dislodged from the back plate **5** of FIG. **1** by the returning gas ions become ionized in the ion source plasma arc column and are extracted as a useful beam **6** of metal ions. The choice of the metal plate **5** to be utilized in the ion source of FIG. **1** depends, of course, upon which metal ion beam it is desired to produce in the operation of the cyclotron. It should be noted that it is necessary to use in the ion source a heavy mass support gas, particularly krypton or xenon, in the operation of the cyclotron to produce the metal ion beam.

The metal ions given in the table below have been successfully accelerated and extracted from the ORIC using the present invention as discussed above.

TABLE

ORIC-EXTRACTED METAL ION BEAMS

Particle	Energy (MeV)	External Beam Current (eμA)
$28_{Si}5+$	80	0.9
$48_{Ti}5+$	47	1.2
$56_{Fe}5+$	40	1.2
$58_{Ni}6+$	56	3.5
$63_{Cu}6+$	51	1.2
$64_{Zn}6+$	51	1.5
$93_{Nb}6+$	35	0.07

Another interesting result was obtained from the acceleration of niobium. With the niobium beam it became possible to completely turn off the xenon gas and the arc became self-sustaining from the niobium ions returning to the source. Turning off the rf voltage on the other hand, eliminated the returning niobium ions and caused the arc to drop out.

Typical arc conditions for the ORIC are 500 volts and 7 amps. Additional arc power may produce higher intensity beams. The metal ion beam output is stable and is controlled by the gas flow and the arc current. When xenon is used, the gas flow is smaller than the argon gas flow for an argon arc. The lifetime of the metal plate is much longer than the cathode lifetime resulting in a maximum possible run life.

It should be understood that the present invention is not limited to the specific metals mentioned above for use as the back plate **5** in the ion source arc chamber, but this plate may be made from any desired metal or a suitable compound to provide the associated metal ion beam. Examples of compounds that could be used for the back plate are: LiF, BN, and MgF_2. Also any compound that can be sputtered could be utilized for the plate **5** to provide for a desired ion beam.

This invention has been described by way of illustration rather than by way of limitation and it should be apparent that it is equally applicable in fields other than those described. For example, it may be utilized in the ion sources of linear accelerators using rf extraction.

What is claimed is:

1. In an isochronous cyclotron provided with a magnetic field, an internal ion source provided with an arc chamber, an accelerating electrode for withdrawing ions from said arc chamber, said accelerating electrode effecting the acceleration of said ions through said cyclotron as guided by said magnetic field, and an ion beam extraction system for extracting a desired separated ion beam from said cyclotron, the improvement comprising providing a heavy mass arc support gas to said ion source selected from the group consisting essentially of krypton and xenon, and providing a plate mounted on the back wall of said ion source arc chamber, said plate constructed from a sputterable material, whereby during operation of said cyclotron said plate is bombarded by returning energetic low-charged gas ions that failed to successfully cross the initial accelerating gap between said ion source and said accelerating electrode such that some of the atoms dislodged from said plate become ionized in the ion source arc column and are extracted from said cyclotron as a useful beam of heavy ions.

2. The cyclotron set forth in claim **1**, wherein said plate is metal selected from the group consisting essentially of silicon, titanium, iron, nickel, copper, zinc and niobium.

3. The cyclotron set forth in claim **2**, wherein said selected support gas is krypton.

4. The cyclotron set forth in claim **2**, wherein said selected support gas is xenon.

5. The cyclotron set forth in claim **2**, wherein said selected support gas is xenon, and said selected metal plate is nickel.

6. The cyclotron set forth in claim **1**, wherein said plate is a compound selected from the group consisting essentially of LiF, BN, and MgF_2.

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