April 2, 1963 C. B. MILLS 3,084,281

ION SOURCE (R.F. INDUCTION TYPE)

Filed Nov. 30, 1956 2 Sheets-Sheet 1

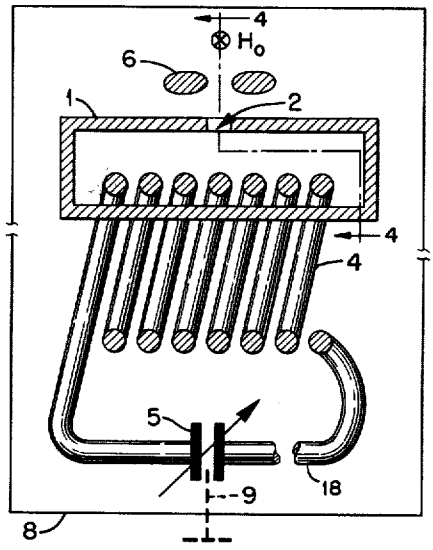


Fig. 3.

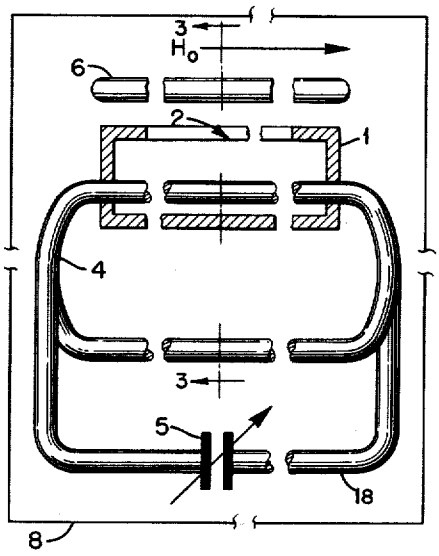


Fig. 4.

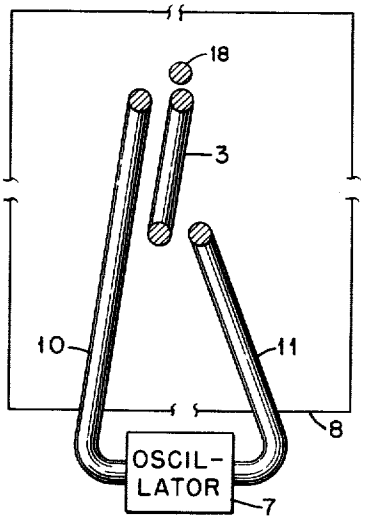


Fig. 1.

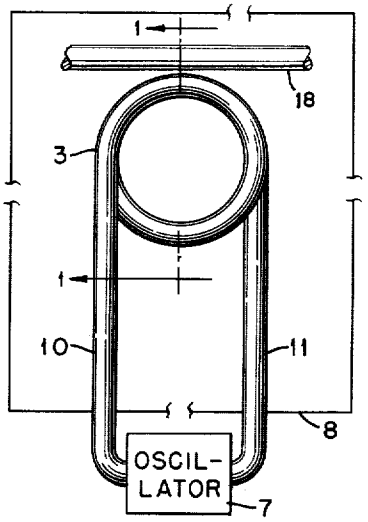


Fig. 2.

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ION SOURCE (R.F. INDUCTION TYPE)

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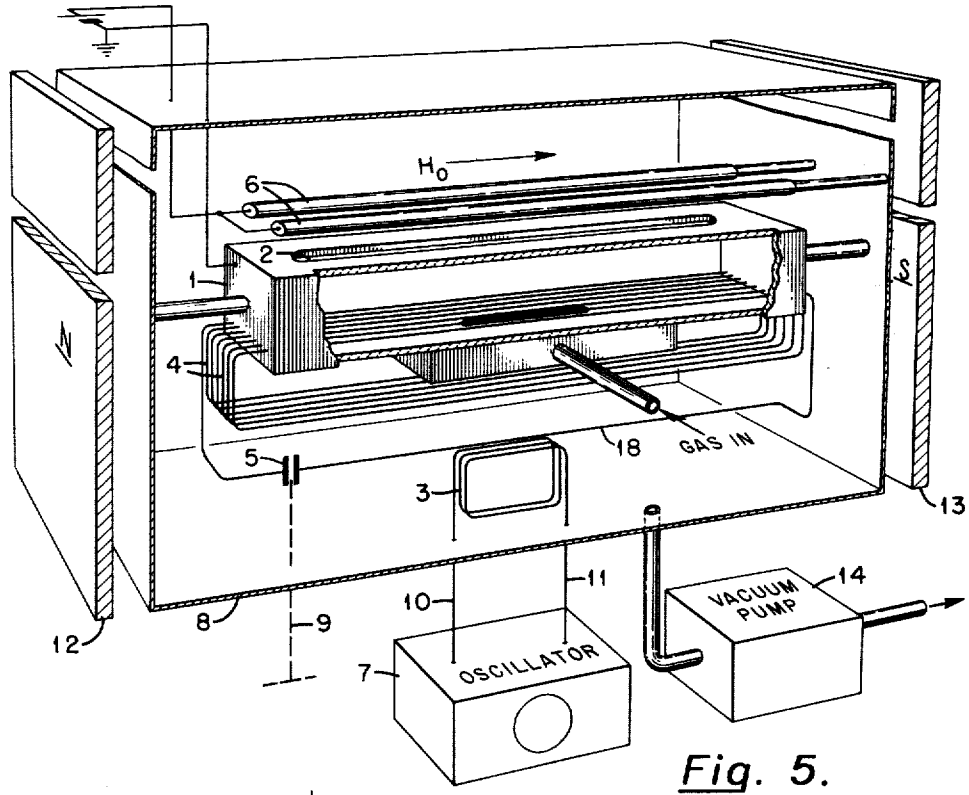


Fig. 5.

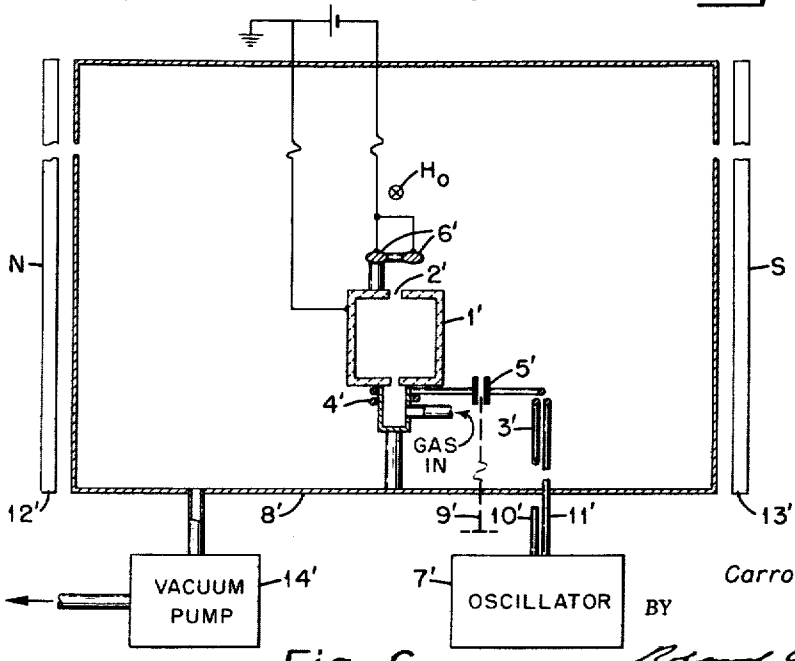


Fig. 6.

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3,084,281

ION SOURCE (R.F. INDUCTION TYPE)

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2 Claims. (Cl. 315—111)

The present invention relates to ion sources, and more especially to a novel means for generating quantities of positive ions for calutrons, cyclotrons, and other ion accelerating machines.

Sources for the production of high energy positive ions and generation of high intensity beams of those ions generally utilize a high-intensity electron current collimated by a strong magnetic field to ionize molecules of a gas in the arc chamber. An arc plasma is formed in the chamber which has a meniscus along that side of the plasma nearest the ion withdrawal aperture. Accelerating electrodes are placed adjacent this aperture and provided with high negative potentials to withdraw large beams of ions from the chamber. One limiting factor in the intensity of the ion beams thus formed is the rate at which power can be fed from an external source into the body of the arc.

When a radio-frequency oscillation is utilized in place of a large electron current to excite the gas molecules, it must be applied to a surface of the arc plasma which is normal to the magnetic field for electrodynamic reasons. The plasma sheath adjusts itself to the applied potential, however, by ambipolar diffusion, so that the R.F. field does not penetrate far into the plasma. Power is then supplied to the arc only by a surface effect of very low efficiency.

In an attempt to overcome certain shortcomings and limitations of the electron beam type ion sources, I propose to ionize the gas within a substantially enclosed arc chamber immersed in a stationary magnetic field and to impart high energies to the particles by means of a second, oscillating magnetic field oriented as described hereinafter. This oscillating field is introduced into an arc chamber containing the gas to be ionized by means of a secondary radio-frequency coil which receives power from a primary coil coupled to an external radio-frequency oscillator. Maxwell's equation describing potential induction by a transient magnetic field may be written:

$$\overline{\nabla}\times\overline{E}=-\frac{\dot{\overline{H}}}{i}$$

where $\overline{\nabla}$ is the gradient operator, $\overline{E}$ is the electric field vector, $\dot{H}$ is the rate of change of the magnetic field H, and c is the velocity of light. I have found a novel R.F. power transfer mechanism can be utilized to create a high-density arc, based upon analysis of the above equation. I have found that when the electric field is created parallel to a constant magnetic field H_0 and the magnetic field is caused to oscillate at a high frequency, as by a high-Q R.F. tank circuit, the oscillating magnetic field will penetrate into the body of the arc, giving a volume excitation which produces much greater quantities of ions than did the prior surface excitation.

Moreover, I have found that if the arc source described hereinafter is rotated ninety degrees in the high intensity constant magnetic field provided (H_0), so that the R.F. magnetic field H is perpendicular to H_0, the ion current density will decrease by at least one order of magnitude, illustrating that the volume effect no longer occurs. However, I have also postulated that a continuous increase of ion energy similar to that in a cyclotron will occur in such orientation of my novel source if the frequency w of the R.F. magnetic field is described by the cyclotron equation $w=H_0l/mc$, where e is the charge, m is the mass of the ion to be heated, and c is the velocity of light. Thus a novel method is provided for increasing the energy of ions within a plasma, similar to the acceleration of ions in a cyclotron. This high energy ion plasma is independent in density from the power supply because of the induction method of acceleration for which space charge limits do not obtain. Thus an arbitrarily high density plasma can be generated with this means and retained by conventional magnetic field geometries.

Accordingly it is an object of my invention to provide a novel ion source utilizing a coil and an electrical oscillation generator to ionize gas molecules in a strong magnetic field. A further object of my invention is to provide a novel, high density, ion source for generating positive ions of relatively high energies. Another object of my invention is to eliminate the filament and associated beam of electrons of the conventional source, to eliminate the problems associated therewith such as filament burnout, shorting, and so forth. It is a primary object of the invention to introduce power into an arc plasma.

These and other objects of my invention will be apparent from the following detailed description of a preferred embodiment thereof when read in connection with the appended drawings, wherein:

FIGURE 1 represents an oscillator and primary coil, as seen from one end.

FIGURE 2 represents the same primary coil as seen from the top.

FIGURE 3 represents one embodiment of my novel ion source linked wtih a secondary coil.

FIGURE 4 represents an end view of the novel source of FIGURE 3.

FIGURE 5 is a sectional view of the ion source; and

FIGURE 6 shows the source oriented at 90° to the direction shown in FIG. 5.

Referring now to FIGURE 1, power for the source may be furnished by a conventional R.F. oscillator **7** connected to a single loop **3** through simple quarter-wave lines **10, 11** extending through suitable insulators in tank **8**. Suitable high currents are obtained with a relatively low oscillator frequency; for example, 2 megacycles per second, but the frequency range of the oscillator is not critical for high density ion sources. Better operation is achieved at higher frequencies, substantially 300 mc. being a suitable frequency. The single loop **3** is coupled to one end of the secondary loop **4** shown in FIGURE 3 and excites the secondary. The voltage supplied by the oscillator system and the R.F. frequency should be so related to the gas pressure within the arc chamber that the amplitude of electron motion is approximately equal to the mean free path of electrons within the arc chamber.

Referring now to FIGURES 3 and 4, the source shown is preferably mounted in a vacuum tank **8** or may be mounted in a tank maintained at high pressure, the object being to prevent power loss to anything but the arc by removing conductors and any region of electrical discharge from the vicinity of the source. The source may comprise an arc chamber **1** made of an electrical insulating material such as lavite formed in a shallow, rectangular, elongated box. A relatively long, thin ion exit slit **2** is provided on the upper surface of the box. An accelerating electrode **6** defining a corresponding slit is placed closely adjacent the ion exit slit and a high negative potential is impressed thereon to accelerate ions that diffuse out of the arc chamber. One side of the secondary R.F. coil **4** may thread the end walls of the arc chamber **1** to form a grid along its long dimension. For ease of construction the coil **4** may contact the lower external wall of the box, instead of passing internally through the box. The external side of the secondary supports a series variable capacitor **5** for tuning. A shaft **9** extends to the out-

side of the vacuum tank so the capacitor may be adjusted. As an example of ion source performance, in an arc chamber having an aperture slit 1/32 inch wide and 6 inches long and provided with an accelerating electrode 1/4 inches away from the ion exit slit, with potentials of 6–11 kilovolts applied between the accelerating electrode and the arc chamber, ion currents between 10 and 26 milliamperes from argon gas were developed. This is a space charge limited current. No clear limit to the ion source production was found.

Referring now to FIGS. 5 and 6, the same parts are provided with primed numbers in FIG. 6. A constant magnetic field is provided by confronting pole pieces **12**, **13**, which may preferably be part of an electromagnet (not shown). Between the pole pieces is disposed the vacuum tank **8** which may be evacuated by a conventional vacuum pump **14**. The arc chamber **1** is mounted within the vacuum tank with its long dimension oriented parallel to the direction of the permanent magnetic field (in FIG. 5) where a large ion output is required, and with its long dimension oriented perpendicular to the constant magnetic field (in FIG. 6) where a high density, high energy arc plasma is desired. Suitable accelerating electrodes **6** are disposed adjacent to and aligned with slit **2** and define a slit through which ions pass upon leaving the arc chamber **1**. The arc chamber is threaded by a coil **4** which terminates in a tuning capacitor **5** having a tuning arm **9** extending through the wall of the tank. Disposed physically adjacent the secondary coil **4** is primary loop or coil **3**. Magnetic flux is generated in the coil **3** by an R.F. oscillator **7**, the frequency of which may be adjusted as desired. The flux from the primary loop energizes the secondary loop which provides an oscillating magnetic field within the arc chamber **1** to initiate a discharge. The oscillating magnetic field induces a correspondingly oscillating electromotive force in the arc. The electrodes **6** are maintained at a high negative potential through a power supply indicated schematically as a battery. Vapor may be admitted to the ion source through a vapor entry slit **16** in the bottom of the arc chamber from any convenient source of gas.

It is thus apparent that I have developed a novel method for supplying energy to an arc discharge by means of an oscillating magnetic field. Other uses for my novel method and apparatus will be apparent to those skilled in the art.

What is claimed as novel is:

1. An ion source comprising an elongated box provided with a vapor entry slot and a longitudinal ion exit slit, an accelerating electrode disposed opposite said exit slit, power supply means coupled to said electrode and said box to accelerate ions out of said exit slit, a source of vapor connected to said entry slot, an elongated secondary coil provided with a plurality of turns threading the length of said box near the bottom wall of said box, a primary coil linked to said secondary coil, means for tuning said secondary coil, an oscillator coupled to said primary coil to energize the same, an enclosure for said source, and said accelerating electrode and said coils, means to evacuate said enclosure and means for establishing a constant, relatively intense magnetic field through said box in a direction parallel to the electric field induced by said secondary coil within said box.

2. In the method of generating ion plasmas which comprises establishing a constant magnetic field through an ionization region, and supplying gas to be ionized into said region, the improvement which comprises first establishing within said region an induced oscillating electric field parallel to said magnetic field to form ions from said gas, and then changing the orientation of said fields within said region from parallel to perpendicular to accelerate said ions to higher energies.

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