ABSTRACT

An electron-bombardment ion source includes a chamber into which a propellant is introduced. The propellant is ionized by means of electrons drawn toward an anode from a cathode. At one end of the chamber is an apertured screen followed by an aligned apertured grid. The grid is maintained at a potential that accelerates the ions out of the chamber through the screen and the grid. A surface within the chamber, such as the screen, the wall of the chamber or both, and other than the anode and cathode, is maintained at a potential approaching the anode during the initiation of ion production, while being maintained at a potential approaching that on the cathode during steady-state ion production. Conveniently, this is achieved by interposing a resistance, of appropriate value, between that surface and a potential source.

14 Claims, 3 Drawing Figures
ELECTRON-BOMBARDMENT ION SOURCES

The present invention pertains generally to electron-bombardment ion sources. More particularly, it relates to circuitry for enhancing the process of initiating the production of ions within such sources.

Electron-bombardment ion sources were originally developed as a means of propulsion in outer space. As compared with conventional chemical rockets, the high exhaust velocities available from such ion sources permit a reduction in propellant mass needed to meet the same propulsion requirement. An earlier version of such an ion source, as developed specifically for space propulsion, is disclosed in U.S. Pat. No. 3,156,090. Various modifications and improvements on such an ion source are disclosed in U.S. Pat. Nos. 3,229,715, 3,262,262 and 3,552,125.

More recently, electron-bombardment ion sources have found use in the field of sputter machining. In that field, the ion beam produced by the source is directed against a target, so as to result in the removal of material from the target. This effect is termed sputter erosion. By protecting chosen portions of the target from the oncoming ions, material may be selectively removed from the other portions of the target. That is, those other portions of the target are thereby selectively machined.

Alternatively, essentially the same apparatus can be used for what is called sputter deposition. In this case, a surface to be coated is disposed so as to face the target in order to receive material eroded from the target. Selected portions of the surface under treatment may be masked so that the sputtered material is deposited in accordance with a chosen pattern. Moreover, several different target materials may be ionically bombarded simultaneously so as to result in a controlled disposition of alloys of the different materials. In some cases, sputter deposition represents the only way in which the formation and deposit of such alloys may be achieved.

Still another use of the described ion sources is in the incorporation of dopant ions into a semiconductor material. Basically, this usage differs from sputter machining only in that higher ion energies are required in order to obtain a useful distance of penetration into the semiconductor material.

Whatever the specific manner of utilization, such ion sources are especially attractive for sophisticated tasks like those of forming integrated circuit patterns. For example, conductive lines may be deposited on a substrate in thicknesses measured in Angstroms and with widths measuring but tenths or hundredths of a micron. Defects in linearity may be held to less than a few hundredths of a micron.

Electron-bombardment ion sources of the kind under discussion include a chamber into which an ionizable propellant, such as argon, is introduced. Within the chamber is an anode that attracts high-velocity electrons from a cathode. Impingement of the electrons upon the propellant atoms results in ionization of the propellant. At one end of the chamber is an apertured screen followed by an apertured grid. A potential impressed upon the grid accelerates the ions out of the chamber through the apertures in both the screen and the grid, while the apertures in the screen are aligned with those in the grid so as to shield the latter from direct ionic bombardment. At least usually, another electron-emissive cathode is disposed beyond the grid for the purpose of effecting neutralization of the electric space charge otherwise exhibited by the accelerated ion beam. Preferably, the interior of the chamber is subjected to a magnetic field which causes the electrons emitted from the cathode to gyrate in their travel toward the anode. This greatly increases the chance of an ionizing collision between any given electron and one of the propellant atoms, thus resulting in substantially increased efficiency of ionization.

A common problem encountered with prior electron-bombardment ion sources has been that of satisfactorily initiating the formation of the ion plasma. In designing the ion sources, the anode shape and the magnetic field configuration are chosen so as to result in good performance in terms of a low discharge-energy loss per beam ion formed with a high fraction of the propellant being ionized. However, the meeting of that objective results in a comparatively poor extraction of electrons from the cathode prior to the formation of a discharge plasma. After initiation of the discharge, the resulting plasma of electrons and ions exhibits a conductivity that permits the anode to be much more effective in extracting electrons from the cathode. In consequence of these considerations, a relatively high potential difference between the anode and cathode has been required in order to initiate the production of ions. After initiation, however, the potential difference can be significantly reduced without causing extinguishment of the plasma discharge. Moreover, it has been necessary to effect such a potential reduction in order to obtain an ion beam which includes a desired high fraction of singly ionized atoms.

Several approaches have heretofore been utilized for the purpose of, at least in effect, creating a high potential difference during starting so as to promote the generation of a useful electron current, while subsequently reducing that potential difference upon the formation of the desired discharge plasma. In perhaps the most direct approach, the ion source is started by impressing a high direct-current potential difference between the anode and cathode. Upon initiation of the plasma discharge, that potential is manually or automatically lowered, as by switching. In another approach, a high-voltage pulse or series of pulses is superimposed, during initiation of discharge, upon the normal or steady-state potential difference supplied between the anode and cathode. A different technique involves control of the magnetic field to which the electrons within the chamber are subjected. In this case, the current supplied to the associated electromagnet is applied only after plasma discharge has been initiated; in the absence of the magnetic field, the coupling between the anode and cathode is increased so as, in turn, to decrease the amount of required additional potential difference necessary to effect the initiation of the production of ions. In all of these various approaches, some kind of active and additional switching or generating device has been required.

It is, accordingly, a general object of the present invention to provide an electron-bombardment ion source with a new and improved starting circuit that overcomes disadvantages or deficiencies present in previous systems.

A specific object of the present invention is to provide a new and improved starting arrangement which eliminates or at least minimizes the need to increase ion source discharge potential difference above its normal steady-state operating value.
Another object of the present invention is to provide a new and improved starting arrangement which employs only passive components and yet which is reliable and economical.

An electron-bombardment ion source constructed in accordance with the present invention includes a chamber for containing and into which an ionizable propellant is introduced. Disposed within the chamber are an anode and an electron-emissive cathode, a potential being impressed between the anode and cathode to effect electron emission at a sufficient velocity to ionize the propellant. Disposed in the vicinity of one end of the chamber is an apertured screen. Spaced from that screen in a direction away from the chamber is an apertured grid, the apertures in the grid being aligned relative to the apertures in the screen so that the screen shields the grid from ion bombardment. A potential is impressed between the grid and both the anode and the cathode so as to accelerate ions out of the chamber through the screen and the grid. Finally, the ion source includes passive means for maintaining a surface, within the chamber but exclusive of the anode and the cathode, at a potential which at least approaches the potential on the cathode during steady-state production of ions within the chamber, while at a potential at least approaching the potential on the anode during the initiation of ion production prior to the existence in the chamber of a discharge plasma.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIG. 1 is a schematic diagram of a known electron-bombardment ion source with its associated electrical circuitry;

FIG. 2 is a schematic diagram of an electron-bombardment ion source and its associated electrical circuitry constructed in accordance with one embodiment of the present invention; and

FIG. 3 is a schematic diagram of an electron-bombardment ion source and its associated electrical circuitry constructed in accordance with an alternative embodiment of the present invention.

In order perhaps to gain a better understanding of the subject matter, an explanation will first be given with respect to the nature and operation of a typical known electron-bombardment ion source as illustrated in FIG. 1. It will initially be observed that FIG. 1, like FIGS. 2 and 3, is set forth in schematic form. The actual physical structure of the apparatus may, of course, vary, but a suitable and workable implementation is that disclosed in the aforesaid U.S. Pat. No. 3,156,090, which patent, therefore, is expressly incorporated herein by reference. Thus, a housing 10 is in the form of a cylindrical metallic shell 12 that circumscribes and defines a chamber 14 in which an ionizable propellant, such as argon, is to be contained. As indicated by the arrow 16, the propellant is introduced into one end of shell 12 through a manifold 18. Disposed symmetrically within shell 12 is a cylindrical anode 20. Centrally positioned within anode 20 is a cathode 22.

In the vicinity of the end of shell 12, opposite that in which, in this case, manifold 18 is located, is an apertured screen 24. Spaced beyond screen 24 is an apertured grid 26. The apertures in screen 24 are aligned with the apertures in grid 26 so that the solid portions of grid 26 are shielded from bombardment of ions that are withdrawn from chamber 14 through screen 24 and grid 26 so as to proceed along a beam path indicated by the arrow 28. As mentioned in the introduction, a magnetic field, indicated by arrow H, preferably is established within chamber 14 as by inclusion of a suitable electromagnet or permanent magnet structure surrounding shell 12. The direction of the magnetic lines of force is such as to cause electrons emitted from cathode 22 to gyrate or convolute in their passage toward anode 20. Situated beyond grid 26 from chamber 14 is a neutralization cathode 30.

As herein embodied, cathodes 22 and 30 are each formed of tungsten wire the opposite ends of which are individually connected across respective energizing sources 32 and 34. Sources 32 and 34 may deliver either direct or alternating current. Other types of cathodes, such as hollow cathode which, during normal operation requires no heating current, may be substituted. For creating and sustaining electron emission from cathode 22, a direct-current source 36 is connected with its negative terminal to cathode 22 and its positive terminal to anode 20. Connected with its positive terminal to anode 20 and its negative terminal returned to system ground, as indicated, is a main power source 38 of direct current. Another direct-current source 40 has its negative terminal connected to accelerator grid 26 and its positive terminal returned to system ground. Finally, one side of neutralizing cathode 30 also is returned to ground. Completing the energization arrangements, both screen 24 and the wall of shell 12 are connected to one side of cathode 22 by leads 42 and 44.

In operation, the gaseous propellant introduced through manifold 18 is ionized by high-velocity electrons flowing from cathode 22 toward anode 20. The pressure within chamber 14 is sufficiently low, of the order of 10^{-4} Torr, that the emitted electrons tend to proceed to anode 20 with a rather low probability of creating ionization of the propellant. However, the magnetic field causes the electrons to gyrate so as to substantially increase the probability of collisions between the electrons and the atoms in the propellant. Ions in the plasma which is thus produced are attracted by accelerator grid 26 so as to be directed along path 28. Screen 24 serves to focus the withdrawn ions so that they escape through grid 26 without impinging upon its solid portions. The resulting ion beam traveling along path 28 is then neutralized in electric space charge by means of the electrons emitted from neutralizing cathode 30. Power source 36 serves to maintain the discharge current between cathode 22 and anode 20. The energy in the ions which constitute the ion beam is maintained by power source 38. Power source 40 supplies the negative potential on grid 26 necessary to accelerate the ions out of chamber 14.

While the various potentials involved will vary depending upon the particular propellant utilized, a typical value for the potential of source 36 is between 10 and 50 volts. The potential difference exhibited by power source 38 has an exemplary value of 500 volts in a sputtering application, 1,000 volts in usage of the ions source for electric space propulsion and 50,000 volts or more for ion implantation. The absolute
potential magnitude of accelerating source 40 is generally 0.1 to 1.0 times that of main power source 38. The current through accelerating source 40 is usually from a small fraction of the ion beam current, often of the order of 0.01 or less. Consequently, the ions beam current is substantially equal to the current delivered from main power source 38. For tungsten filaments, cathode heating potentials are typically of the order of 5 to 15 volts. The discharge power involved, the potential from source 36 times the current delivered thereby, generally ranges from about 200 to 1,000 watts per amperle of ions formed in the ultimate ion beam. 

For space propulsion, neutralizer 30 is always required. In other applications, such as in sputtering, it may be possible to omit neutralizer 30. For example, with the ion-impinged target connected to the system ground, neutralizer 30 may not be required in cases in which a comparatively low ion beam current is involved.

To initiate the production of ions within chamber 14, it is necessary to impress a high potential difference between cathode 22 and anode 20. That starting potential may be either a steady direct current or a pulse. Alternatively, or in combination, the applied magnetic field strength may be decreased. In any event, the effective initial potential difference must usually be between 50 and 100% higher than the desired steady-state operating value as discussed in the introduction.

A known alternative mode of operation involves omitting leads 42 and 44 so that shell 12 and screen 24 are isolated electrically instead of being held at the potential of cathode 5. Because the electrons existing within the plasma produced are considerably more mobile than the ions, shell 12 and grid 24 quickly reach a potential, during steady-state operation, such that most of the electrons within chamber 14 are reflected from the shell and the screen. Those elements thus reach an equilibrium floating potential which is near the potential of cathode 22. Steady-state operation of the ion source is, therefore, normally substantially the same as in the actually illustrated case in which both the shell and the screen are returned to the cathode potential. However, the starting performance in such a modified arrangement, with leads 42 and 44 omitted, is likely to be erratic. This arises at least in part because the various insulating supports which have to be included tend to become high-value resistances after prolonged operation. Consequently, the potentials which then exist on the inner walls of shell 12 and screen 24 may range anywhere between the various potentials that exist on adjacent elements prior to the initiation of a discharge plasma.

Implementation of the improved features to which this application is directed requires but very small physical change in the system depicted in and described with respect to FIG. 1. For purpose of illustration, therefore, the ion sources illustrated in FIGS. 2 and 3 are constructed in what is essentially the same manner as that of FIG. 1. That is, the ion sources of FIGS. 2 and 3 again include a shell 12 that defines a chamber 14 into which a propellant 16 is introduced so as to be subjected to ionization by electrons traveling from a cathode 22 toward an anode 20 under the influence of a magnetic field H. Also included are screen 24, accelerator grid 26 and neutralizer 30. Moreover, essentially the same power sources 32, 34, 36, 38 and 40 are associated with the physical structure and so connected as to create and cause the flow of a beam of ions along path 28.

In addition, however, the ion sources shown in FIGS. 2 and 3 include means for maintaining a surface, within chamber 14 but exclusive of anode 20 and cathode 22, at a potential which at least approximately approaches the potential on the cathode during steady-state production of ions within chamber 14 and at a potential that at least approaches the potential on anode 20 during the initiation of ion production prior to the existence in chamber 14 of a discharge plasma. While that surface may be a separately incorporated conductive element located within chamber 14, it most conveniently and simply is one or both of the inner wall of shell 12 and screen 24.

Completing the improved arrangement, a source of potential difference has its negative end coupled to cathode 22 and its positive end invariably coupled to the aforementioned surface. To this end, as shown in FIG. 2, the necessary added element is simply a resistor 50 connected at one end to the positive terminal of discharge potential source 36 and at its other end both to the wall of shell 12 and the structure of grid 24. In the modified arrangement of FIG. 3, a first resistor 52 is connected at one end to the positive terminal of source 36 and at its other end to the wall of shell 12, while a second resistor 54 is connected at one end to that positive terminal of source 36 and at its other end to screen 24. Although a separate source of potential, suitably returned at its negative end to cathode 22, could be used for connection to resistor 50 or resistors 52 and 54, it is at least usually more economical to employ the already-present source 36 for the purpose at hand. In any event, the lower end, as drawn, of the resistance or impedance is connected to a source of potential which at least is approximately the same as that applied to anode 20.

Resistor 50, or resistors 52 and 54, are selected to have a value of resistance sufficiently large that, during normal steady-state operation of the ion source, shell 12 and grid 24 are maintained at a potential at least close to that of cathode 22. Consequently, the resistor or resistors carry only a small fraction of the current from discharge power source 36 with the result that steady-state performance of the ion source is substantially the same as described in connection with FIG. 1. On the other hand, the value of resistance is sufficiently low that enclosure 12 and screen 24 are maintained at a potential close to that on anode 6 during starting, prior to the full initiation of a discharge plasma, when the level of electron emission from cathode 22 is comparatively low. Thus, during the initial space-charge-flow condition that exists before a discharge plasma is present, cathode 22 is surrounded by a surface or surfaces at least substantially at the potential of the anode. This situation promotes electron emission from cathode 22 so as more quickly and efficiently to initiate the actual production of ions. As the level of electron emission rises during the starting process, the potentials on shell 12 and screen 24 rapidly approach their steady-state values which are at least near the potential on cathode 22. Accordingly, the shell and screen are first at a potential which is most conducive to starting the plasma discharge in spite of very low electron emission, but such potentials change to that which is consistent with efficient operation as the electron emission rises toward the normal operating level.
For any given physical embodiment of the overall ion source, of course, the exact value of resistance required can best be determined by simple trial measurements. For an exemplary electron discharge of two amperes current at a discharge potential of 50 volts in a 10-centimeter-diameter chamber containing argon, a resistance value of 5,000 ohms has been found to be sufficiently low to permit proper initiation of ion production at the desired steady-state discharge voltage of the value of 50 volts. Under such starting conditions, the potential drop across the impedance of the resistor is quite substantially less than the potential difference which exists between anode 20 and cathode 22. Moreover, the initiation of ion production was found to be independent of the presence or absence of the potentials from source 38 and 40, which potentials were respectively of typical values of 500 volts and 100 volts. This contrasted with the operation of the prior system of FIG. 1 in which the initiation of the production of ions proves to be more difficult under the application of the high voltage applied to accelerator grid 26. At the same time, the 5,000-ohm resistance value was found to cause no significant adverse effect on steady-state performance when compared to the otherwise similar operation of the system of FIG. 1. This lack of deterioration in performance arises because less than 1% of the electron emission from cathode 22 is conducted through the resistance.

It is evident that substantially improved starting performance of the ion source is obtained in accordance with the disclosure. Yet, the significant improvement in performance is attainable by means of what may be only the addition of a single resistor, while considerably more complex active components, such as a pulse source or a switching mechanism, may be eliminated.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. An electron-bombardment ion source comprising:
   means defining a chamber for containing an ionizable propellant;
   means for introducing said propellant within said chamber;
   an anode disposed within said chamber;
   an electron-emissive cathode disposed within said chamber;
   means for impressing a potential between said anode and cathode to effect electron emission at a sufficient velocity to ionize said propellant;
   an apertured screen disposed in the vicinity of one end of said chamber;
   an apertured grid spaced from said screen in a direction away from said chamber with the apertures in said grid being aligned relative to the apertures in said screen so that said screen shields said grid from ionic bombardment;
   means for impressing a potential between said grid and both said anode and cathode for accelerating ions out of said chamber through said screen and said grid;

2. An ion source as defined in claim 1 in which said surface includes said screen.

3. An ion source as defined in claim 1 in which said surface includes the inner wall of said chamber.

4. An ion source as defined in claim 1 in which said surface includes both said screen and the inner wall of said chamber.

5. An ion source as defined in claim 1 in which said maintaining means includes a source of potential difference, means for coupling the more negative end of said source to said cathode, and means for varyingly coupling the more positive end of said source to said surface.

6. An ion source as defined in claim 5 in which said source of potential is in common with said means for impressing a potential between said anode and cathode.

7. An ion source as defined in claim 1 in which said maintaining means includes impedance means connected at one end to said surface and maintained at its other end at a potential positive with respect to said cathode, said impedance means exhibiting a resistance sufficiently large that, during said steady-state production, current flow through said impedance means is but a small fraction of the current flow delivered by said means for impressing a potential between said anode and cathode, with said resistance yet being sufficiently low that, during said initiation of ion production, the potential drop across said impedance means is very substantially less than said potential difference between said anode and cathode.

8. An ion source as defined in claim 1 in which said surface includes said screen and in which said maintaining means includes a resistor connected between said screen and a source of potential positive with respect to said cathode.

9. An ion source as defined in claim 1 in which said surface includes the inner wall of said chamber and in which said maintaining means includes a resistor connected between said inner wall and a source of potential positive with respect to said cathode.

10. An ion source as defined in claim 1 in which said surface includes both said screen and the inner wall of said chamber, and in which said maintaining means includes a resistor connected at one end to both said screen and said inner wall and connected at its other end to a source of potential positive with respect to said cathode.

11. An ion source as defined in claim 1 in which said surface includes both said screen and the inner wall of said chamber, and in which said maintaining means includes a first resistor connected at one end to said screen and a second resistor connected at one end to said inner wall with the other ends of both said resistors being connected to a source of potential positive with respect to said cathode.

12. An ion source as defined in claim 1 in which said maintaining means includes an impedance connected at one end to said surface and maintained at its other end at the potential on said anode.
13. An ion source as defined in claim 1 which further includes neutralization means located beyond said apertured grid from said chamber for neutralizing the electric charge in ions flowing through said grid.

14. An ion source as defined in claim 1 which further includes means for developing a magnetic field within said chamber to effect gyration of electrons emitted from said cathode.