Development of broad beam ion sources at CSSAR

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High-energy and intense beam current broad beam ion sources have been developed for ion implantation and dynamic recoil mixing at CSSAR. The sources can be operated over beam energy and current ranges of 3–120 keV and 5–70 mA, respectively. For sputter coating of thin films, a series of focusing beam ion sources with different structures has also been developed. The energy and current range from 1–10 keV and 100–350 mA for different applications. For some applications, low-energy (below 100 eV) ion beams are required. CSSAR has developed a 6-cm-diam broad beam ion source. The source can be operated at beam energy 10–70 eV, and the beam current 15–80 mA has been extracted. Typical structures and operational data are given for the sources mentioned above. Recently a new type of broad beam metal ion source (Electron Beam Evaporation Metal Ion Source EBE) is being studied. Ion beams of several kinds of materials such as C, W, Ta, Mo, Cr, Ti, B, Cu, etc. have been extracted from the source. Typical operation conditions and ion yields are given in this paper.

I. INTRODUCTION

CSSAR has developed the broad beam ion sources for more than 25 years. The objective was initially aimed at space applications such as station keeping and attitude control of the satellite. It has been changed to aim at ground base applications, especially for material modifications, since 1981. A series of high-energy (up to 120 keV) broad beam ion sources for ion implantation and dynamic recoil mixing, a series of focusing beam ion sources with or without using dished grids for sputter coating of thin films, and a low energy (as low as 10 eV) broad beam ion source for low-energy reaction etching and assisted deposition of optic thin films have been developed since then. More than 50 broad beam ion sources have been designed and manufactured for different applications. Recently a new type of broad beam metal ion source is being studied. In this paper these sources will be described.

II. HIGH-ENERGY BROAD BEAM ION SOURCES

Broad beam ion sources, being developed for space applications, are now available for producing beams of various shapes and sizes. These sources can be made to produce high and uniform density beams that would be particularly well suitable to ion implantation of large surfaces in a short time. In addition, they tend to be simple and cheap to build, and easy to maintain and operate. However, conventional broad beam ion sources have been operated at considerably lower accelerating voltages (usually 1–3 kV) than those associated with implantation and cannot be used for this purpose directly. Therefore we developed a series of high-energy broad beam ion sources for this purpose. The typical ion source designed for ion implantation is shown in Fig. 1. The features of this source are the special designed discharge chamber which can prevent the discharge from extinguishing when flashover between grids occurs during high extraction voltage operation by the magnetic fields formed in the chamber, and the special designed insulator structure which can eliminate the flashover which often occurs between grids in high extraction voltage ion source. So the extraction voltage as high as 120 kV can be sustained for long periods of operation time without any problem. This voltage is well suitable for ion implantation but much higher than those used for space applications. A simple two-grid ion extraction system was used in this source. The grids can have single and/or multiapertures depending on the desired beam shape and size. Table I shows the typical data. The beam energies and currents extracted from this source range from 3 to 120 keV and 5 to 70 mA for argon and nitrogen. A beam uniformity ranging from ±10% to ±20% is achieved within a 25-cm-diam circle at the location 60 cm downstream of this source.

III. MAGNETIC CONVERGENCE FOCUSING ION SOURCE

For industrial applications, a high sputter coating rate is required. The dished grids are capable of high beam...
TABLE I. Typical data of high-energy broad beam ion source for seven apertures.

<table>
<thead>
<tr>
<th>Extraction voltage (kV)</th>
<th>Beam current (MA)</th>
<th>Discharge voltage (V)</th>
<th>Discharge current (A)</th>
<th>Flow rate (sccm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>120</td>
<td>60</td>
<td>50</td>
<td>2.3</td>
</tr>
<tr>
<td>N₂</td>
<td>70</td>
<td>70</td>
<td>50</td>
<td>2.0</td>
</tr>
<tr>
<td>Ar</td>
<td>3</td>
<td>15</td>
<td>50</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Current density in a small target area to get a high coating rate but are more difficult to fabricate than flat grids due to the difficulty of machining thin spherical shapes in graphite and to form such shape with molybdenum sheet. For this reason we developed a new type of focusing beam ion source. A 3.8-cm-diam ion source is shown in Fig. 2. The discharge chamber of this source has two anodes and two refractory tungsten filaments are used for cathode emitters and special cusp magnetic fields are designed to control the beam spot area by magnetic convergence. It is found that in this source the beam spot area and beam current density on the target at the location downstream of the source can be substantially affected when the geometry and strength of the cusp magnetic fields are changed. Under certain condition, a very steep beam current profile can be formed. The beam spot diameter as small as 5 cm and beam current density over 20 mA/cm² at the same location as using dished grids have been obtained with a simple flat grid accelerator system. Typical beam profile is shown in Fig. 3. Beam current over 350 mA has been extracted from this source. The highest beam energy is 10 keV. The sputter coating rates 2.5 Å/s for C, 7.5 Å/s for Ti, and over 15 Å/s for Al have been obtained.

IV. LOW-ENERGY BROAD BEAM ION SOURCE

Low-energy (below 100 eV) ion beams have recently been used for such applications as ion beam oxidation, low-energy reaction etching, and assisted deposition of optic thin films. It is difficult to extract such ion beams from conventional broad beam ion source because the extractable beam current densities are low at these energies. Moreover, generally the minimum ion energy is also limited by the discharge voltage. We have developed a 3.6-cm-diam low-energy broad beam ion source. The schematic diagram is shown in Fig. 4. With this source, low-energy ion beams ranging from 10 to 70 eV can be extracted by biasing the screen grid potential to be negative to the ground at small grid separation distance with improved...
TABLE II. Typical data of low-energy broad beam ion source.

<table>
<thead>
<tr>
<th>Screen grid voltage (V)</th>
<th>Acceleration grid voltage (V)</th>
<th>Discharge voltage (V)</th>
<th>Discharge current (A)</th>
<th>Beam energy (eV)</th>
<th>Beam current (MA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-34</td>
<td>-300</td>
<td>44</td>
<td>0.7</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>+36</td>
<td>-500</td>
<td>34</td>
<td>2.0</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

magnetic field design. The beam currents extracted from the source are 15–80 mA. Beam current densities ranging from 0.15 to 0.67 mA/cm² are measured at a location 20 cm down stream of the grids. typical data are shown in Table II.

V. ELECTRON BEAM EVAPORATION BROAD BEAM METAL ION SOURCE (EBE)

For the purpose of material modifications, intensive beams of both gaseous and metal ions are necessary. Ion sources for producing high current gaseous ions are now available, but the development of metal ion sources for this purpose has just begun. CSSAR has developed a new type of broad beam metal ion source (EBE). A schematic diagram is shown in Fig. 5. In this source we use a focusing electron beam to bombard and vaporize the metal within the same chamber where the metal atoms are ionized by arc discharge. The discharge occurs between filament and an anode. The electron beam extracts from the discharge and is focused to a high beam current density by magnetic fields, which then bombards the crucible that the metal contains, so that a very high temperature area can be obtained on the crucible center and a high density metal vapor is formed and the discharge can be sustained without using support gas. A two-grid accelerator system is used to extract the ion beams. Ion beams of several kinds of materials such as C, W, Ta, Mo, Cr, Ti, B, Cu, etc. have been extracted from the source. The source can be operated with either gas or solid materials. Because of the use of a focusing electron beam in our metal ion source, the temperature in the crucible can be high enough to vaporize any element which is compatible with vacuum environment even if refractory materials are used. So the ions of many species can be obtained from this source. It is also expected that metal compounds can be formed on the target surface where gaseous and metal ions bombard by introducing reactive gases into the source chamber during operation, and the preliminary test has shown that titanium nitride can be formed by this way. The beam currents which have been extracted from a 4-cm-diam ion source are 20–70 mA at a beam energy 4 keV. The operational data and ion yields are shown in Table III.

VI. SUMMARY

Several series of broad beam ion sources have been developed at CSSAR for different applications, and recently a new type of broad beam metal ion source is being studied. The source can be operated with either gas or solid materials and both solid material with gas. So metal compounds can also be formed by this source. So far intense metal ion beams (up to 70 mA) have been extracted from this source for several materials which include C, W, Ta, Mo, Cr, Ti, Cu, B, etc., and titanium nitride has been obtained by directly deposition with this source.