Production of Fine Ion Beam from Solid Metal Target by a Narrow High Power Density Electron Beam Bombardment

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Production of Fine Ion Beam from Solid Metal Target by a Narrow High Power Density Electron Beam Bombardment

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An ion source bombarded with fine electron beam was studied for several targets (Zn, Se, Si). The apparent source diameter was about 0.5 mm and resulted brightness was of the order of $10^8 \sim 10^9$ A/m·strad. And this ion source brightness could be controlled by the grid bias potential like the triode gun.

1. Introduction

In recent years great attention has been held in the field of ion physics, particularly with respct to applications in semiconductor ion implantation.[1] Generally ions are injected into a semiconductor substrate through a mask. If excellent fine ion sources are developed, it is possible to inject any ion into the substrate without the mask. And in other fields for instance microanalysis of surface structure a fine ion beam is required to increase the resolution.[2] Methods to produce ions are extremely versatile in contrast with the electron emission.[3] Up to now the universal method has not been developed. Particularly in order to make ions, vapourizing and ionizing processes are necessary. Often an oven has been used to ionize neutral gas atoms. If two processes take place simultaneously it is quite convenient to produce metal ions.

The high power density laser beam[4],[5] or electron beam may be able to evaporate metals in short time.[6],[7] In the case of laser beam bombardment the ionization process will be thermal for its high temperature but for electron beam bombardment the collision with electrons will be dominant for its low temperature. And these beams can be focused into a fine point, so a fine ion source will be expected.

In this report, the authors present a fine metal ion source by fine electron beam oblique bombardment. The produced ions were extracted by three electrode immersion lens system. The used power density was of the order of 10^4 W/cm^2 which was extremely lower compared with the case of laser injection over 10^{10} W/cm^2. The extraction voltage was of the order of 10 KV and got $10^8 \sim 10^9$ A/strad·m^2 as the normalized brightness. And the diameter of focused ion beam was of the order of $0.4 \sim 1.1$ mm.

2. Brightness of an Ion Source

Quality of an ion source is represented by many properties i.e. total ion current,

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divergence of beam, diameter of ion source, velocity distribution, mass contents and state of charge. At first the most important property for a gun is the brightness of ion source. The brightness is defined as follows,

$$B=j/\pi\beta^2=I_i/\pi r_c^2\pi\beta^2 \quad \mathrm{A/strad\cdot m^2} \tag{1}$$

where j is the ion current density at the source in $\mathrm{A/m^2}$, β the semi-aperture angle of the ion beam in radian, r_c the radius of source and I_i the total ion current. And j is given by

$$j=\rho v=qe\sigma nv, \tag{2}$$

where ρ is the charge density, v the velocity of ion, q the number of charge, e the charge of electron, n the total density of atoms and σ is the ratio of number of ions to total atoms. The normalized brightness B_n is defined as follows if $v \ll c$

$$B_n=(c/v)^2 B \tag{3}$$

where c is the velocity of light. If eV is the kinetic energy of ion, M is the mass number of ion and m_o is the mass of proton. B and B_n will be rewritten by

$$B=\sqrt{2}\,\sigma q^{3/2}e^{3/2}nV^{1/2}/\pi m_o^{1/2}M^{1/2}\beta^2 \quad \mathrm{A/strad\cdot m^2} \tag{4}$$

$$B_n=c^2\sigma q^{1/2}e^{1/2}nm_o^{1/2}M^{1/2}/\sqrt{2}\,\pi\beta^2V^{1/2} \quad \mathrm{A/strad\cdot m^2}. \tag{4$'$}$$

For the single charged ions it follows

$$B_n=3.31\times10^{-7}\cdot\sigma nM^{1/2}/\beta^2V^{1/2} \quad \mathrm{A/strad\cdot m^2}. \tag{5}$$

Thus the brightness and normalized brightness depend on the mass of ion, accelerating voltage V and aperture angle β. The highest values reported up to now have been of the order of $10^{11}\sim10^{12}$ A/strad·m² for H_2 ion and of 10^{10} for the metal ions.

3. Experimental Apparatus

The diagrams of experimental apparatus are shown in Fig. 1 and Fig. 2. The electrons emitted from three electrode electron gun with hair pin cathode were focused by the magnetic lens onto a large area target at an angle of almost 20° to the target surface. The accelerating voltage of incident electrons was mainly in the range of 6 kV~12 kV. The diameter of electron beam was 0.3 mm and the used samples were Se, Zn and Si which were able to vapourize with comparatively low power injection density. Of course these metal sheets were degassed in a vacum chamber. The bombarding current was varied from 20 μA to 1000 μA. Ions were produced by the collision of evaporated atoms with injecting electrons or secondary electrons. The process of thermal ionization may be thermal ionization may be negligible in our case.

Thus generated ions were extracted by three electrode immersion lens system. The ion current and secondary electrons were controlled by the potential of grid electrode G as shown in Fig. 2. If the potential of extractor $|V_E|$ is higher than the electron cathode potential $|V_K|$, the reflected electrons from target metal will not be mixed with extracted

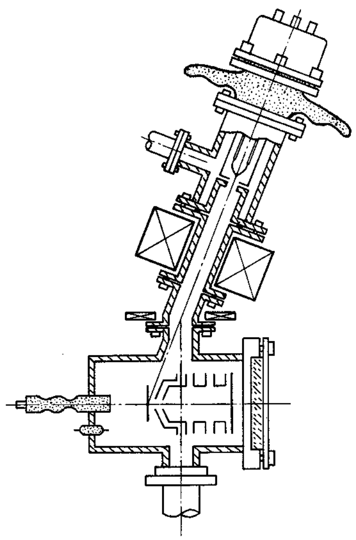

Fig. 1. Section figure of used appatus.

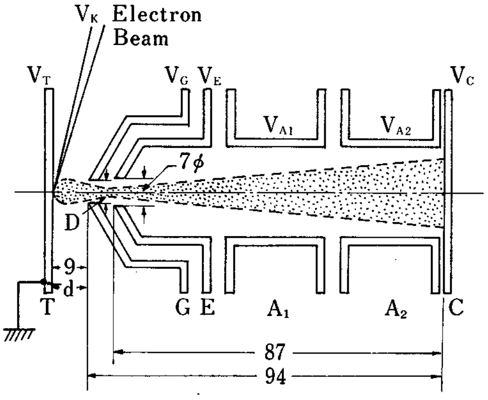

Fig. 2. Electrodes of ion gun system.
T: Target, E, A_1, A_2: Unipotential focusing lens system, G: Grid, E: Extractor, C: Collector or flourescent screen, V_K: Electron cathode potential, V_G: Grid potential, V_E: Extractor potential, V_{A1}, V_{A2}: Lens potential, V_T: Target potential (usually earthed).

positive ions. The ratio of total secondary electrons to primary reached about 50%. And the presence of reflected electrons was demonstrated by a simple experiment. This immersion lens system may make a cross over or a waist which is conceived as a true ion source. This minimum cross section was imaged on a flourescent screen by the unipotential lens E, A_1 and A_2.

4. Extraction System

The characteristics of this ion gun were partly governed by the property of the used immersion lens. Therefor the potential distributions in this lens were examined with a resistance net-work and the trajectories of charged particle were calculated with the computer. An example of path is shown in Fig. 3 in which the initial velocity was postulated

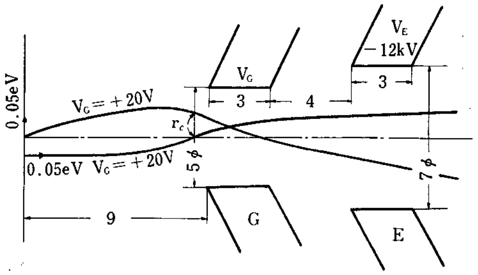

Fig. 3. Examples of ion path near target.
Solid line 1: No initial tangent,
Solid line 2: 45° initial tangent.

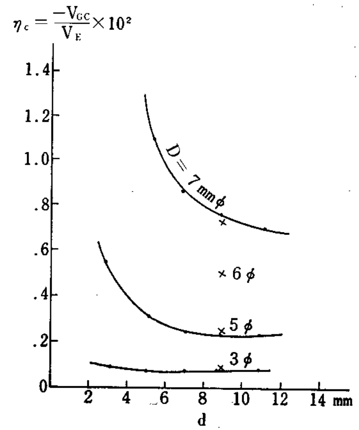

Fig. 4. Grid cut off potential V_{GC} versus target-grid hole distance d.

for 0.05 eV. If ions are produced near the target surface only, the cut off voltage can be defined from the axial potential distribution. The relation of the cut off voltage versus target-grid distance 'd' is shown in Fig. 4 in a function of grid diameter 'D' as a parameter.

5. Aperture Angle of Ion Beam

The aperture angle of ion beam was measured from the photograph of ion image on the flourescent screen without the focusing lens. Photograph 1 shows an example of ion image on the screen. Microphototrace of these films fitted to the gaussian distribution. If the region containing 95% of total current is defined as the beam width and the source position is at the target center, the aperture angle will be able to be measured.

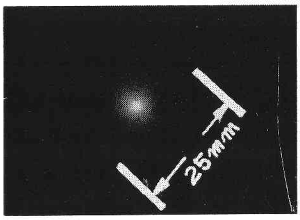

Photo. 1

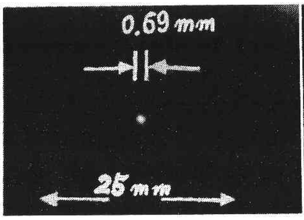

Photo. 2

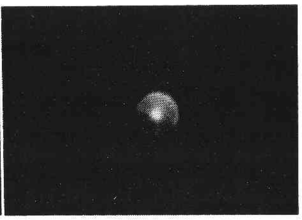

Photo. 3

Photo. 1. Image pattern of ion beam without focusing lens near cut off bias potential. (Here cut off does not mean true ion beam cut off)

Photo. 2. Focused image of above image.

Photo. 3. Focused image of ion beam at deeper bias than cut off potential.

6. Diameter of Minimum Cross Section of Ion Beam

The cross over diameter $2r_c$, as was shown in Fig. 3, was obtained from the measurement of the minimum image on the flourescent screen by changing the center electrode potential V_{A1} of the unipotential lens system. Photograph 2 shows an example of focused ion beam image. Of course characteritics of the focusing lens was studied. From this study the apparent position of the cross over point was assumed approximately to be on the target plane. The true position of cross over was present near the grid surface. And the true diameter of cross over point is given by the apparent diameter multiplied by $(\varphi_1/\varphi_2)^{1/2}$, where φ_1 and φ_2 are the potentials of cross over point and flourescent screen. The value of φ_1 is reduced from the path and potential distribution. Then the true diameter of minimum cross over was of the order of 0.5 mm. Measured apparent cross over diameter is shown in Fig. 5 together with the other data.

7. Ion Current

The ion current was measured by Faraday cup using focusing lens. Figure 7 shows the relation of the measured ion current versus bombarding electron current. Of course the ion current, I_i, is also a function of the extractor potential $|V_E|$, and the collector

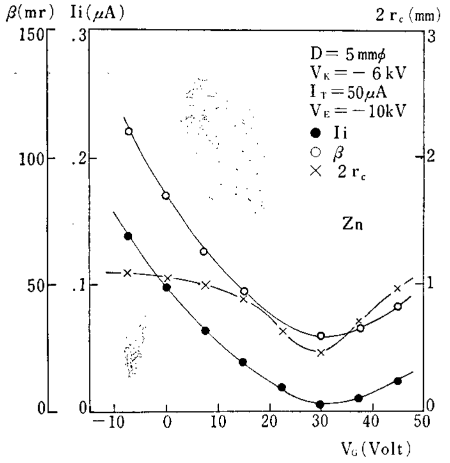

Fig. 5. Aperture angle β, cross over diameter $2r_c$ and ion current I_i versus grid bias potential.

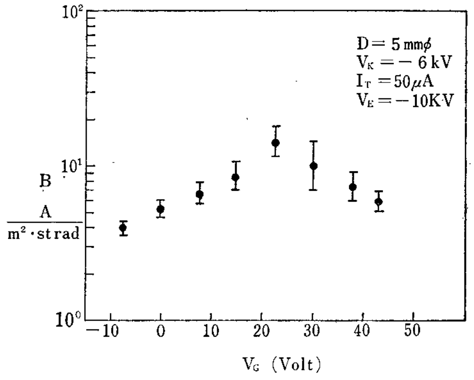

Fig. 6. Brightness B versus grid bias potential.

current includes secondary electron as was mentioned in the above section if $|V_E|$ is smaller than $|V_K|$. The positive ions and negative electrons could be separated by the electric deflection field. The ratio of ion current to bombarding electron current was smaller than a part of thousand at maximum.

8. Brightness

From the values of aperture angle β, beam minimum diameter $2r_c$ and ion current I_i, the brightness B can be calculated using Eq. (1). Figure 5 shows the experimental results of β, $2r_c$ and I_i against the grid bias. As can be seen from the figure, the minima of

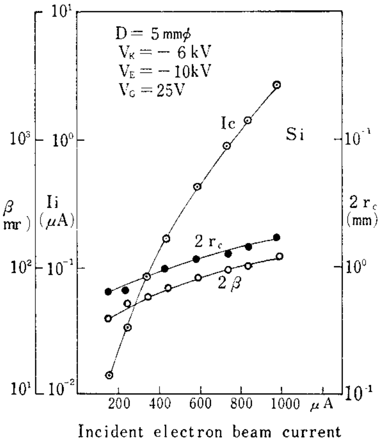

Fig. 7. Aperture angle β, cross over diameter $2r_c$ and ion current I_i versus bombarding electron current at brightness peak condition as shown in Fig. 6.

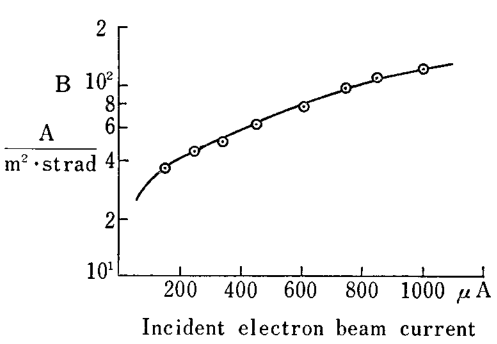

Fig. 8. Brightness versus bombarding current.

curves appear at a value of grid potential mentioned in section 3. Figure 6 shows the brightness versus grid bias. Usually the three electrode gun shows the maximum brightness at a whenelt cylinder potential for the immersion cathode lens charactersitics, in this ion gun the resulted brightness also shows the maximum value at a grid bias potential. At this maximum condition, with increasing the bombarding electron current, the peak brightness B varies as shown in Fig. 8. This figure does not show saturation property under our experimental region, but steeper increase in brightness with increasing of bombarding electron current will not be expected.

9. Results and Discussion

The above sections show the possibility of the method to get the fine metal ion beam. The normalized brightness was of the order of $10^8 \sim 10^9$ A/strad·m^2. This value was not high but the ion current density focused by the lens was 30 μA/cm^2, which was of the same order as in other metal ion sources. But to be controllable by the grid bias may be valuable. Though the ion current at the deep grid bias potential may be produced as a result of collision of neutral atoms with secondary electrons from the target, the authors will not discuss it precisely here. And under the poor bombardment power density, the evaporation of metal was intermittent as water boiling. As the intervals between evaporations were shortened with increasing the injection power density, the observed ion current became near the continued value.

Of course the samples were degassed in vacuum chamber near melting point but occluded gases were not degassed perfectly. But the ratio of aimed metal ions to total ions would be not less than several percent. The mass analysis and the velocity distribution were not measured in our case.

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