研　究　速　報
特 集 10
UDC 621.923.048.7

Low-Energy High-Current Ion Source for Ion-Shower Applications
低エネルギ大電流イオンシャワー源

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1. Forewords

Ion-milling technique using ion-shower equipments has become practical in several applications, including surface cleaning, fine machining and thinning. However, the removal rate is generally not very high comparing with other dry etching processes. Recently, this became one of the main problems.

For instance, a lower ion-energy than usual 500 eV or 1keV is desirable when very little damage on the machined surface is required. But, in such case the low extraction voltage results in a low current density of the ion-beam. Together with the lower sputtering yield, it makes the application impractical.

Concerning with Kaufman-type ion-shower equipments, following conclusion is found in previous studies [1], [2]. That is; although Child's law shows that the current density increases proportionally to the density of the holes in the grid, it saturates when the diameter of the apertures is very small, for instance, less than 2mm. But, the reason of this phenomenon has not been explained yet.

Authors made test on this point and obtained a hopeful result for realizing high efficiency extraction of ion-beam.

2. Experiments

Ion extraction characteristics were tested with a Kaufman type ion-shower system.

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Total beam current, beam current density at the machining surface and divergence angle are included in the tested parameters.

Tests were made on conventional two-grid system, single grid system and some specially designed grid systems.

A rotary pump and an oil-diffusion pump with liquid nitrogen trap are used in the vacuum system. The working chamber has its quantity of 18 litre and is pumped up to 7×10^{-7} Torr before argon gas is provided into the discharge chamber (plasma chamber). The pressure in working time was adjusted to give sufficient and minimum plasma density for obtaining the maximum beam current which varied according to the test condition.

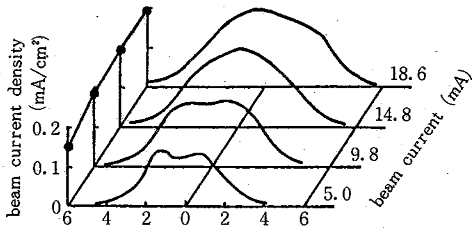
Beam current density was measured with a Faraday-cup array with nine probes. The diameter of each probe is 3 mm. The array can be rotated. The distance between the center of the rotation and center of the array is 132mm. This feature makes it possible to measure 2-dimensional beam profile finer than with a fixed array.

2.1 Two grid system

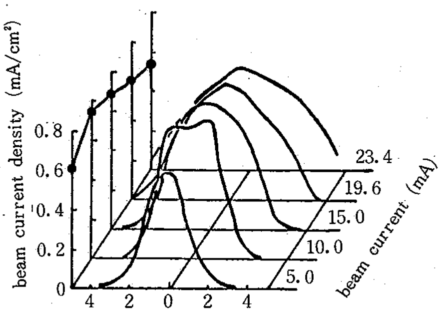
Grid sets are made of graphite, and round extracting holes are made to be a hexagonal array.

In preliminary tests, it was found impractical to apply the ratio lg/ds(lg: distance between the two grids, ds: diameter of the holes in the grid) which is more than 1 or less than 0.5. Therefore, most experiments were carried out with grid sets which were assembled as lg/ds=0.6.

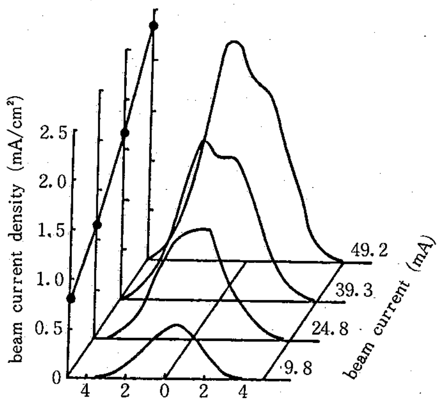
Beam divergence characteristic was estimated by the beam divergence angle which was defined by Aston et al. [1].



(a)　ds=3.0mm　lg=1.8mm
Vt=550V　Vn=450V
Ical=28.6mA



(b)　ds=2.0mm　lg=1.2mm
Vt=550V　Vn=450V
Ical=23.4mA

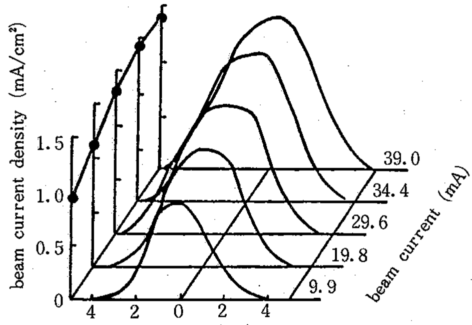


(c)　ds=1.0mm　lg=0.6mm
Vt=550V　Vn=450V
Ical=71.6mA

Fig. 1 Difference of beam profiles with various grid sets.

The results of the test are as follows.

Figures la to 1c show the beam profiles of the three grid sets, in which the diameters of holes are changed from 3mm to 1mm. Each curve shows the change of the beam current density along a line across the center of the beam. Figures on the horizontal axis



ds=1.0mm　lg=1.0mm
Vt=550V　Vn=450V
Ical=35.0mA

Fig. 2 Beam profile with a 1 mm-hole grid set with 1 g/ds=1.

shows the distance from the center. The distance of the measuring plane from the accelerating grid is 100mm.

Accelerating voltage and suppresser voltage were kept constant. The maximum theoretically expected current(Ical) is different from one another. It is proportional to the number of extracting holes.

Following results are led from the figures.

1) Beam current density increases when the hole density of the grid increases.

2) Peak of the beam current density increases when total beam current is increased. However, it saturates when a grid with 3mm-holes or 2mm-holes is used. In these cases, beam divergence angle increases when the total current is larger than the saturating or maximum point of the peak current density.

3) Theoretical maximum beam current could be obtained only with the grid set with 2mm-holes.

The reasons were thought to be followings.

The uniformity of the plasma was not good enough in case of using the grid with 3mm-holes, the effective area of which is too large and is not the same as the other two grids.

The grid with 1mm-holes had tendency to cause break down of insulation probably by the effect of space charge in the working chamber.

As one of the reason which limited the beam current was thought to be the insufficiency of neutralizing electrons, a test was made, changing the neutralization.

The result shows that the increase of the neutralization gives slight improvement on the current density, and a distinctive effect on suppressing the beam divergence.

As the reason of the limitation of current density with 1mm-hole grid seemed to be the break down of insulation, lg/ds was changed to 1, and the effect was observed.

In this case, as shown in Figure 2, the total current and the current density obtained was quite ideal, and the theoretical value (Ical) was realized.

The results shown above indicates that Child's law can basically be applied to small extracting holes, the diameter of which is smaller than 2mm, for instance, 1mm.

Experiments with lower accelerating voltages also supported this argument.

2.2 Single grid system

As the main reason which limits the beam current in use of two grid systems was the difficulty in production of the grid set with severe tolerance introduced by the decrease of the hole diameter, keeping its similarity, a single grid seemed to be hopeful [3].

A single grid with holes, of which the diameter is 0.2 mm (actually, it was hexagonal holes), was tested.

This extractor showed a good performance in the range of very low voltage. For instance, more than 1 mA/cm^2 of ion current density was obtained with 100 V of total accelerating voltage.

However, in this system a large part of total current inevitably flows into the grid itself, resulting in quick wear of the thin grid construction.

2.3 Single grid with insulating layer

To reduce the effect of the grid current described above, a single grid which is modified by coating SiO_2 film on its surface (up-stream side) was tested.

The ion extracting efficiencies (ratio of beam current to the total current including the grid current) of the single grid with and without insulating layer is shown in Figure 3. It demonstrates the effectiveness of the insulating layer. It is specially mentioned that the extracting efficiency exceeds the geometrical transparency in the conditions with sufficient neutralization.

This type of extractor could be one of the solutions for low energy high current ion sources. However,

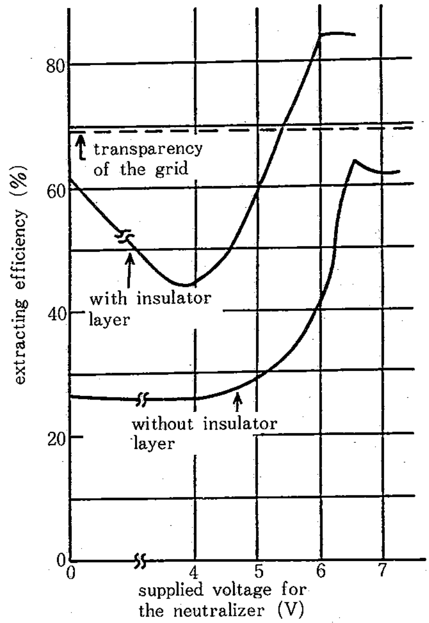


Fig. 3 Effect of the insulator layer on the extracting efficiency.

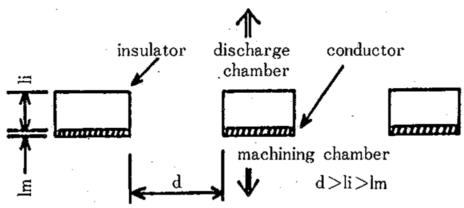


Fig. 4 Sectional view of the insulator substrate grid.

the insulating layer had a tendency to allow cracks during operation, reducing the effectiveness. Therefore, further investigations are necessary to introduce this grid system into practical use.

2.4 Insulator-substrate grid

A new type of grid is tested next. A fundmental shape is illustrated in Figure 4. This grid is thought to be a modification of two-grid system, filling the grid-space with insulator and removing the screen grid. Although it seems to be possible to describe it as an inverted type of a single grid with insulating layer, the extracting mechasism is quite similar to the two grid system. Therefore, the dimensions are essencially importent with this grid.

In this grid the insulator acts as the spacing, and the suface charge controls the plasma-shieth in similar manner to that of a screen grid.

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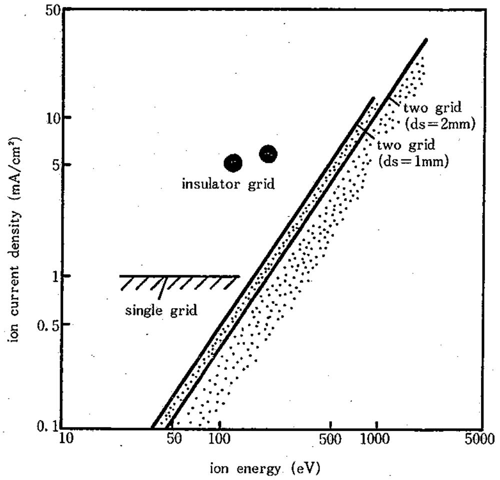

Fig. 5 Comparison of ion-extracting Efficiency between insulator grid and known grid systems

Experimental result obtained by an insulator-substrate grid which is made of Al_2O_3 bulk and Ni film with 0.4 mm-diameter holes was satisfactory.

5 mA/cm^2 and 120 eV ion beam was extracted with this grid, and the current is comparable to the calculated maximum value by simulation as a two-grid system which has the same geometry.

The beam divergence characteristic is also comparable to that of two-grid systems.

This type of grid will be useful not noly for low energy high current application but also for conventional operating range.

Performances in ion-energy and ion-current density using various grid systems are compared in Figure 5.

Three lines indicate the practical upper limits with those grid systems. Two thick dots indicate the excellent feature of the insulator-substrate grid realized in this work.

3. Conclusion

Several types of grid systems were tested of their applicability in low-energy high current ion sources.

Theoretical possibility of conventional two-grid systems was confirmed. However, following two types were found to be more hopeful ones because of their high performance and simpler structure.

1) Single grid with insulating layer. 2) Insulator-substrate grid.

Especially, the insulator-substrate grid was found to be promising for its possibility of wide application.

(Manuscript received, November 30, 1983)