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TECHNICAL PAPER proposed for presentation at Third International Conference on Electron and Ion Beam Science and Technology sponsored by the Electrochemical Society
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ABSTRACT

An ion extraction system for low voltage mercury electron-bombardment thrusters using a glass coating fused to a perforated metal grid is described. A helium diffusion process which eliminates most of the bubbles in the glass coating has been found that greatly increases the effective dielectric strength of the glass and allows acceptable low voltage ion extraction. Grid fabrication techniques and experimental performance results are also discussed.

INTRODUCTION

Applications for electrostatic ion thrusters at specific impulses of 3, 000 seconds or less, appear promising (ref. 1). This is mainly because photovoltaic solar cells may be the only flight qualified power source readily available and suitable for near term application, and a relatively low specific impulse is necessary to maximize the payload with the high specific mass of solar-cell power sources.

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Previous Kaufman thrusters have been optimized at higher specific impulse. Some thruster modifications are required to assure optimum performance at low voltage (net accelerating voltages of 1000 volts or less). The component that would require the most redesign is the ion accelerator grid system.

Recent tests of a composite accelerator grid system indicate the possibility of substantial performance gains over the conventional double grid ion extraction system (ref. 2). A composite accelerator grid system is one in which an electrical insulator is placed in close proximity or in contact with a metallic accelerator grid. The insulator, in effect, replaces the screen grid which separates the plasma in the discharge chamber from the acceleration region in the conventional grid system.

Results of tests on composite accelerator grids are reported herein. First, background information is given with emphasis upon the fused-glass type of composite accelerator grid. Next, in the theory section a helium diffusion process is described which helps to eliminate large bubbles normally found in the fused glass coating. A brief description of the fabrication procedure for constructing a fused glass composite grid is then given followed by a discussion of experimental results.

BACKGROUND

A section view of a Kaufman, or electron-bombardment, ion thruster is depicted in Fig. 1. Typically, mercury vapor is fed into the ionization chamber by passing it through a distributor plate. The atoms of the vaporized gas are then bombarded by electrons emitted from the cathode. The path length traveled by electrons going from the cathode to the anode is greatly increased by the axial magnetic field thus causing much more ionization by electron-bombardment. Ions in the near vicinity of the screen grid have a high probability of being accelerated through the holes in the screen and accelerator grid because of the high electric fields present there. After the ions accelerate through the grid system (thus producing a thrust) electrons are injected to neutralize the exhaust beam. Detailed information concerning the thruster and neutralizer can be found in Refs. 3 and 4 respectively. The screen grid of the conventional double grid system shown in Fig. 1 serves the purposes of containing the discharge plasma and forming the necessary ion optics to prevent direct impingement of the accelerated ions on to the accelerator grid.

Section views of a conventional double grid system and a fused glass composite accelerator grid are compared in Figs. 2(a) and (b). In the conventional system, the plasma sheath is formed at the upstream surface of the screen grid. In the composite grid system the sheath is believed to form near the upstream surface of the insulator. Because of the high electrical resistance of the insulator, charges can build up on the surface forming a virtual screen grid. In this way the sheath is moved closer to the negative accelerator, thus increasing the field strength for a given voltage and consequently increasing the ion beam current density. A close up view of the glass coated side and uncoated side of a typical fused glass composite grid is shown in Figs. 3(a) and (b).

Some advantages of a fused glass composite grid system over the conventional double grid system for low voltage thruster operation are as follows:

1. Close spacing and accurate alinement of the screen and accelerator grids during assembly is no longer required. Also, the grids cannot become misalined by warpage during thruster operation. This leads to the possibility of large diameter accelerator systems previously considered impractical for low voltage operation.

2. The single, glass composite grid does not require match drilling of screen and accelerator holes. Therefore, prepunched sheet can be used for the metallic portion.

3. A reduction in weight of the accelerator grid system is possible with elimination of the screen grid and use of a simplified support structure.

4. The discharge chamber power loss is reduced because of the enhanced ion extraction capability (ref. 5). Two possible factors contributing to the increased ion current density for a given voltage are (a) the increased field strength previously mentioned,

and (b) an increase in the sheath area available for ion extraction.

Some of the factors that had to be considered before these potential advantages could be realized are discussed below.

For efficient thruster operation, the accelerator electrode should be as close as possible to the discharge chamber plasma to permit the highest possible ion extraction rate. As a result the composite grid glass thickness should be only as thick as needed to prevent electrical breakdown through the glass. (The electrical potential which is applied across the glass is approximately the net accelerating potential, V_I, plus the magnitude of the accelerator potential, V_A.) There is a high probability though, that bubbles formed in the glass coating during fabrication will enhance the occurrence of electrical breakdown through the glass. In fabrication the glass is slurry sprayed onto the molybdenum grid, which is then heated in an inert atmosphere to fuse the glass particles together and to the grid. The fusing of the glass particles encapsulates gas. Bubbles are thus formed which, in turn, reduce the effective electrical breakdown strength of the glass. The gas encapsulation could be reduced by vacuum fusing, but various gas liberating mechanisms tend to make the glass to boil and fill in the grid holes with the foaming glass. Alternatively, the electrical breakdown strength could be increased by applying additional glass coatings to the grid, but there is a well defined thickness beyond which grid holes will fill in if more glass is applied.

One obvious answer to this dilemma is to eliminate the bubbles in the glass coating. A procedure to accomplish this has been developed and will now be presented.

THEORY

If the glass is applied such that the maximum glass radius, $r_{g,max}$, is greater than the hole radius, r_h, (see Figs. 4(a) and (b)) then the molten glass surface tension will collapse the walls of the hole during the fusing process. It was show in Ref. 6 that the maximum glass thickness, $L_{g,max}$, for stable hole walls depends on the metal hole radius, r_m, fraction open area, F_m, of the metal grid and the thickness, L_m, of the metal grid. The relationship can be written as

$$L_{g,max} = r_m \sqrt{\frac{\pi}{6F_m\sqrt{3}}}\left[1 + \sqrt{1 - \left(2 - \sqrt{\frac{6F_m\sqrt{3}}{\pi}}\right)^2}\right] - L_m \tag{1}$$

Figure 5 is a plot of the stability limit relationship as a function of fraction open area of the metal grid.

In addition to applying glass coatings up to the stability limit, a further increase in the electrical breakdown strength can be achieved through the use of a helium diffusion process which eliminates nearly all the bubbles. This process consists of fusing the powdered glass in a helium environment which produces helium bubbles in the molten glass. Then, while the grid is still hot, the helium environmental gas is replaced with argon. This causes a high helium concentration gradient in the molten glass since the helium partial pressure in the bubble is atmospheric pressure plus that due to the surface tension of the bubble surface, while at the same time there is a near zero helium partial pressure above the glass surface. The rate of helium diffusion has been found to be sufficient to collapse the bubbles initially formed in the glass. The following equation, which is derived in Ref. 6, relates bubble radius and diffusing time.

$$t' = \frac{1}{2K}\left\{r_{B,0}^2 - r_{B,t}^2 - \frac{4\gamma}{3P_0}\left[r_{B,0} - r_{B,t} - \frac{2\gamma}{P_0}\ln\left(\frac{2\gamma + P_0 r_{B,0}}{2\gamma + P_0 r_{B,t}}\right)\right]\right\} \tag{2}$$

Figure 6 is theoretical plot of bubble radius, $r_{B,t}$, at time, t', for a glass temperature of 1444° K (1171° C) and a typical initial bubble radius, $r_{B,0}$, of 10^{-4} meters. For this calculation, the helium diffusion coefficient of Corning glass code 7052 at 1444° K is $K \cong 4.56\times10^{-11}$ m²/sec, the surface tension of Corning glass code 7052 is $\gamma \cong 2.73\times10^{-1}$ N/m, and the atmospheric pressure is $P_0 \cong 1.01\times10^5$ N/m². As the bubble radius decreases the surface tension forces greatly increase the helium bubble pressure thus enhancing the rate of diffusion and the rate of bubble collapse as shown by the change in slope of the curve in Fig. 6. The time for bubble collapse to zero radius is obtained from Eq. (2) by setting $r_{B,t} = 0$ and is given by

$$t'_c = \frac{1}{2K}\left\{r^2_{B,0} - \frac{4\gamma}{3P_0}\left[r_{B,0} - \frac{2\gamma}{P_0}\ln\left(1 + \frac{P_0 r_{B,0}}{2\gamma}\right)\right]\right\} \tag{3}$$

This collapse time, t'_c, is plotted as a function of the initial bubble radius in Fig. 7.

The times given in Figs. 6 and 7 are for helium diffusion at 1444° K. The corresponding time, t, at other temperatures, T_B, is found by simply multiplying the time t' by the factor t/t' as given by Fig. 8. This figure takes into account the temperature dependence of the helium diffusion coefficient for Corning glass code 7052.

GRID FABRICATION PROCEDURE

As a result of theoretical and experimental investigations a suitable fused glass composite grid fabrication procedure has been developed. It is given in detail in Ref. 6 and briefly described below for a molybdenum grid to be coated with Corning glass code 7052.

1. Determine stability limit from Fig. 5.

2. Deburr the grid and wash it with water then acetone.

3. Glass bead blast entire grid and oxidize it is an electric oven at 538° C for 5 to 10 minutes until a blue or purple surface coloration is present.

4. Sand oxide layer off the downstream face of the molybdenum grid.

5. Slurry spray the upstream face of the grid with a solution consisting of equal parts (by volume) of water and powdered glass.

6. Set the grid on a clean oxidation resistant tray or edge support it in the oxidation resistant environmental control box as shown in Fig. 9 and put lids on the box without any sealing material in the trough. Note that the box has two lids each with its own gas feed system. This arrangement minimizes the amount of back diffusion of oxygen to the grid.

7. Fuse the glass coating following the time environment sequence given in Fig. 10 using inert gas purging rates of approximately 6×10^{-4} m^3 per second per meter of lid perimeter.

8. For each additional coating repeat steps 4 to 7.

9. Sand the downstream face of the grid to expose the molybdenum surface before operation in a thruster.

EXPERIMENTAL RESULTS

The effectiveness of the bubble reduction process can be seen from a comparison of Figs. 11(a) and (b) which are photographs taken looking normal to the glass surface with the molybdenum surface underneath. The glass coating shown in Fig. 11(a) was fused in an argon atmosphere. The amount of bubble collapse is neglibile. Figure 11(b) shows a bubble-free glass coating that was fused using the helium diffusion process. The effective breakdown strength of the bubble free glass was measured to be 8.75×10^{7} v/m (for glass coating thicknesses of approximately 0.4 mm) which is more than a factor of 8 improvement over the glass coatings made using only an argon environment.

Figure 12 is a close-up photograph of the glass coated side of a grid fabricated using the bubble reduction process. The photograph was taken after the grid was operated for more than 200 hours on a 5 cm diameter thruster with no degradation in performance. Operating conditions were: net accelerating potential, 400 volts; accelerator potential, -225 volts; ion beam current, 0.032 amperes; and accelerator drain currents of about 0.002 amperes .

As can be seen in Fig. 12 sputtered material accumulated in some regions where the glass surface was close to or in contact with the discharge plasma. However, even in these regions the hole walls remained clean. Apparently the rate of mercury ion sputter-cleaning of the glass hole walls exceeded the rate of deposition of the sputtered material.

Larger diameter fused glass composite grids, such as the one shown in Fig. 13, have been fabricated. This grid is mounted on a 30 cm diameter thruster and has approximately 12,400 prepunched holes. An optimization program for a 30 cm diameter thruster is presently being conducted at Lewis by Robert T. Bechtel. A typical thruster operating point is given below:

Parameter	Value
Net accelerating potential	1000 volts
Accelerator potential	-700 volts
Ion beam current	1.5 amperes
Accelerator drain current	0.07 amperes
Discharge chamber power loss	250 electron volts per beam ion
Propellant utilization efficiency	0.80

The accelerator system was found to give satisfactory performance over a range of net accelerating potentials from 400 to 1100 volts. At these low net accelerating potentials at least partial neutralization of the exhaust ion beam by means of a hot wire or a plasma bridge neutralizer was found necessary for stable thruster operation in both the 5 and 30 cm thruster tests.

Vibrations developed during launch of a glass grid thruster system might easily excite drum modes of oscillation for the flat grids shown in Figs. 12 and 13. Some shake tests have been conducted and the small diameter glass coated grids for 5 cm thrusters have withstood shake tests exciting the drum modes of oscillation at levels up to 30 g's of random noise (20 to 2000 Hz) and 40's of sinusoidal oscillation (39 to 3, 000 Hz). For these tests the grid was clamped rigidly at its edges beyond a 6.7 cm diameter circle. The fundamental drum mode of oscillation was found to be at 967 Hz. A considerable amount of rigidity can be added to the glass coating by dishing the molybdenum grid prior to glass coating. Figure 14 is a photograph of a dished glass coated grid for a diameter thruster. The grid has a radius of curvature of 44.6 cm and is held in place by a retaining assembly around its outer edge. Detail of the retaining assembly are shown in Fig. 15. The two molybdenum rings are fused together with glass which provides both mechanical support and electrical isolation for the grid. The glass insulation is extended into the first row of holes so that a portion can be kept clean by ion bombardment. Otherwise sputtered material would creat a breakdown path along the surface. This grid is currently being tested on an operating thruster.

CONCLUDING REMARKS

This paper briefly described the recent results of a composite grid program for low voltage, mercury electron-bombardment ion thrusters. Major considerations and findings of the program are listed below.

1. The fused glass composite grid is a potentially attractive grid system for low voltage thrusters because it eliminates several spacing, alinement, and fabrication difficulties present in conventional double grid systems.

2. Glass can be applied to the grid up to a well defined limit that is a function of the metal grid's hole radius, thickness, and fraction open area.

3. A procedure for minimizing the occurrence of bubbles in the glass coating has been developed.

4. Fused glass grids have been successfully fabricated and operated in 5, 15, and 30 cm diameter thrusters. Tests of more than 200 hours of grid operation have given no indication of failure.

5. A fused glass composite grid for a 5 cm diameter thruster has withstood shake tests exciting the drum mode of oscillation at levels of 30 g's of random noise (20 to 2000 Hz) and 40 g's of sinusoidal oscillation (39 to 3000 Hz).

6. A glass coated grid has been fabricated which is dished for rigidity and has an electrically isolated mounting system as an integral part of the grid. It is now being tested on an operating 15 cm diameter thruster.

REFERENCES

1. D. J. Kerrisk, and H. R. Kaufman, AIAA Paper 67-424 (1967).
2. S. Nakanishi, E. A. Richley, and B. A. Banks, AIAA Paper 67-680 (1967).
3. R. T. Bechtel, G. A. Csiky, and D. C. Byers, AIAA Paper 68-88 (1968).
4. V. K. Rawlin and E. V. Pawlik, AIAA Paper 67-670 (1967).
5. P. M. Margosian, NASA TM X-1342 (1967).
6. B. A. Banks, (Proposed NASA Technical Note in process).

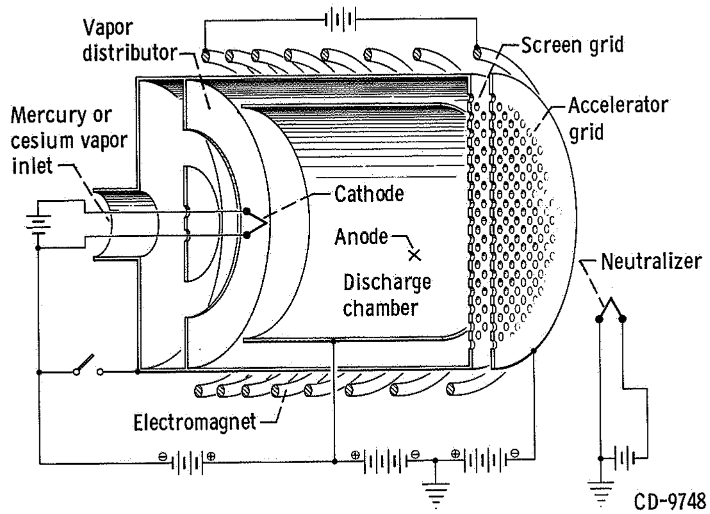
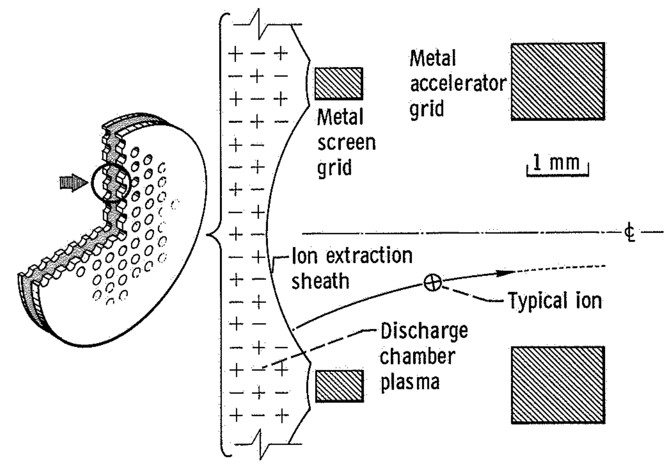
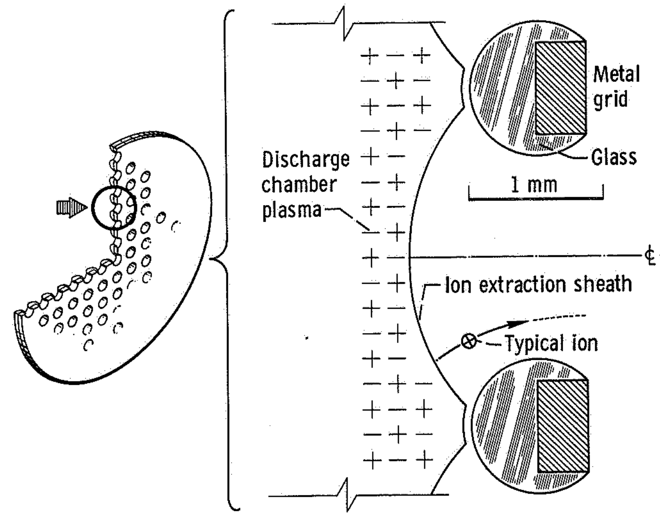


Figure 1. - Section view of the basic Kaufman, or electron-bombardment ion thruster.



(a) Conventional double grid system.



(b) Fused glass composite accelerator grid.

Figure 2. - Accelerator grid systems.

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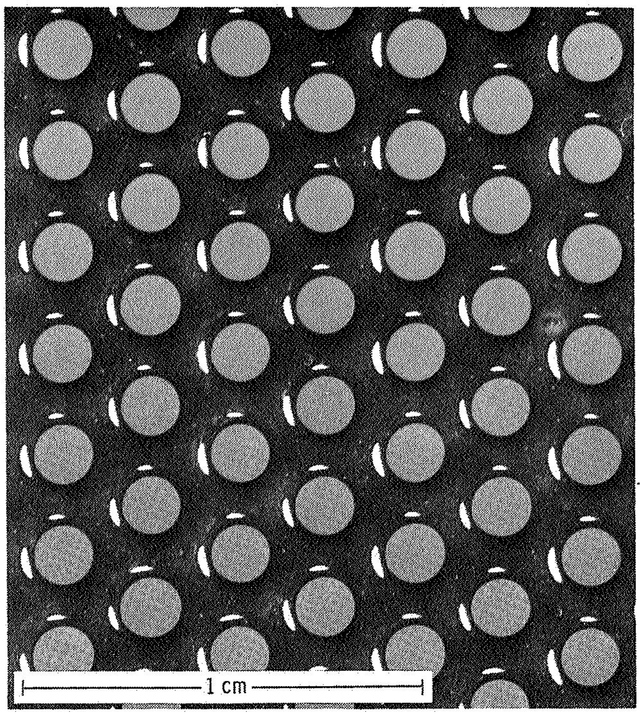
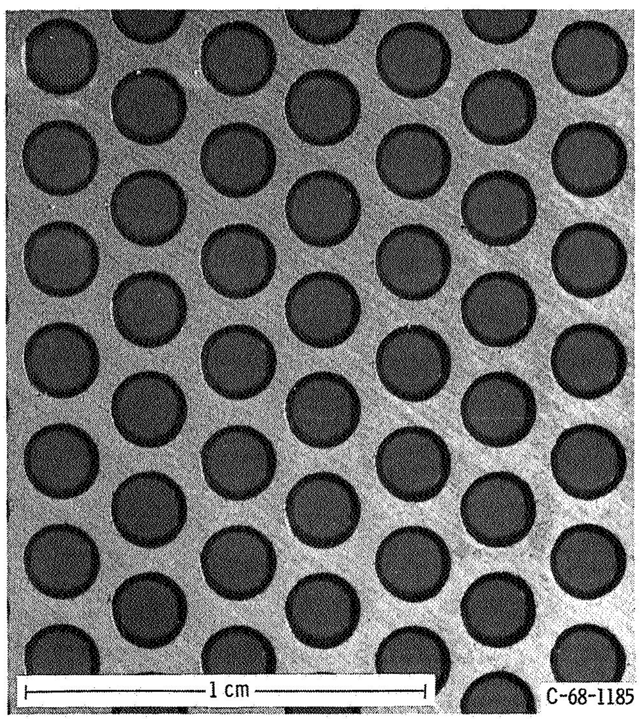
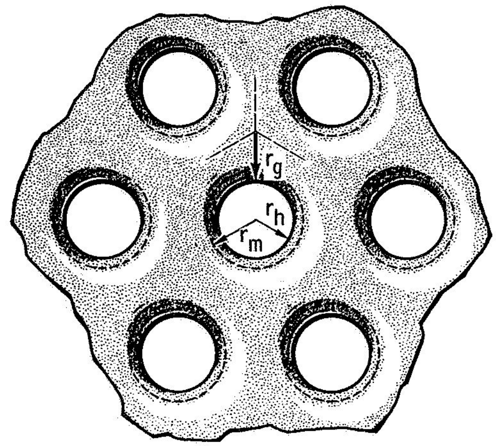


(a) Glass coated side.

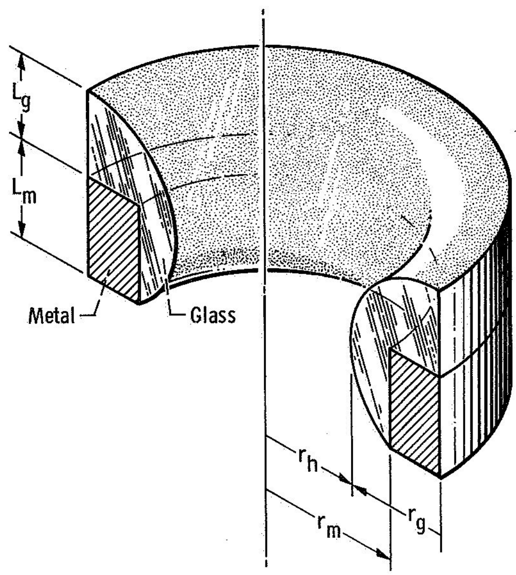


(b) Uncoated side showing molybdenum substrate.

Figure 3. - Fused glass composite accelerator grid.



(a) Face view.



(b) Perspective view.

Figure 4. - Fused glass composite grid parameters.

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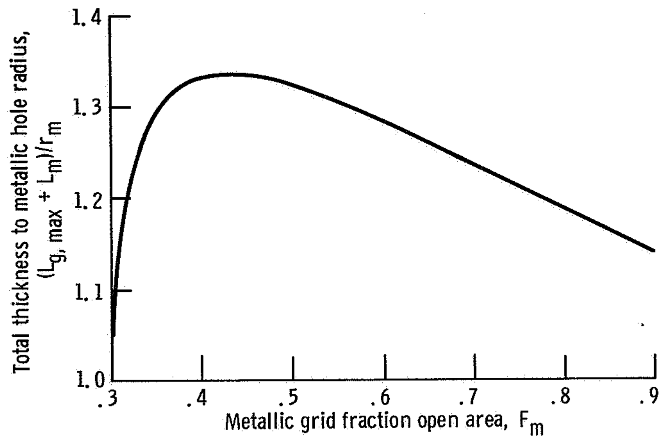

Figure 5. - Ratio of total fused glass composite grid thickness to metallic grid hole radius as a function of the metallic grid fraction open area for stability limited coatings (Eq. (1)).

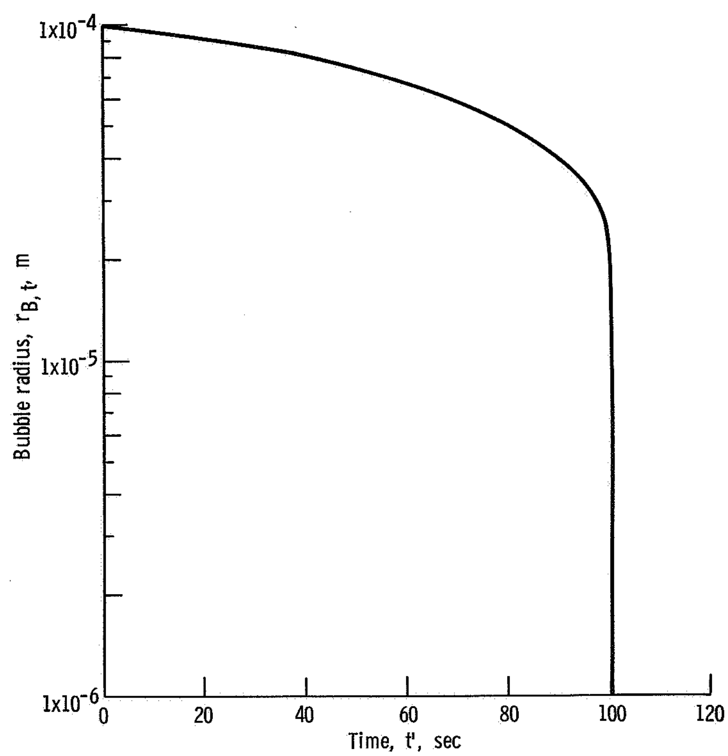

Figure 6. - Bubble radius, $r_{B,t}$, as a function of diffusing time, t' (Eq. (2)). Initial bubble radius, $r_{B,o} = 10^{-4}$ meters. Glass temperature, $T_B = 1444°$ K (2140° F).

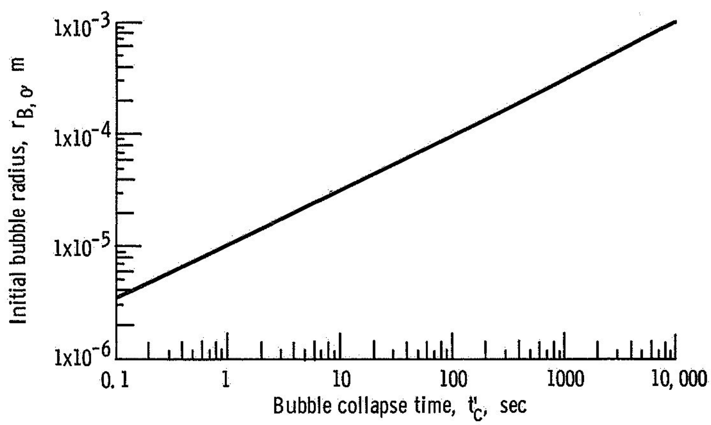

Figure 7. - Bubble collapse time, t_c', as a function of initial bubble radius, $r_{B,o}$, for a glass temperature of 1444° K (2140° F).

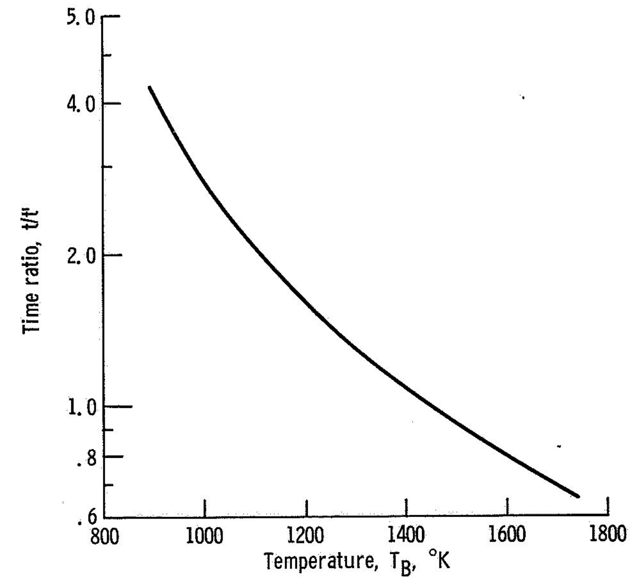

Figure 8. - Ratio of bubble collapse time at temperature T_B to collapse time at 1444° K as a function of temperature.

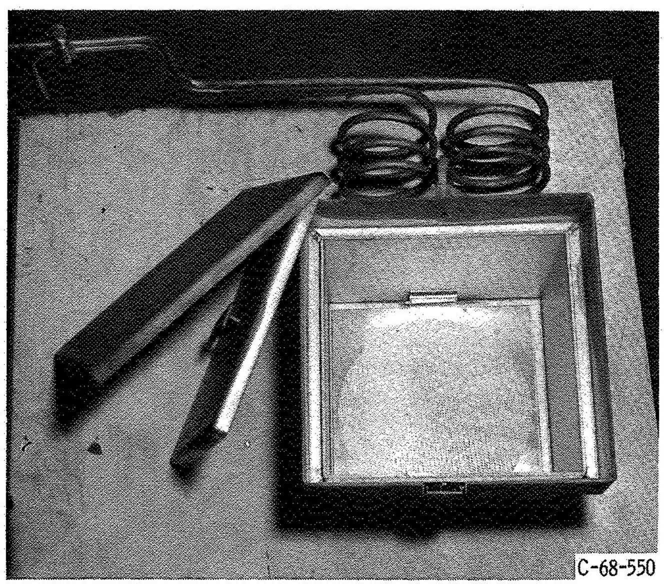

Figure 9. - 15 cm diameter grid in the box used for environmental control during fusing.

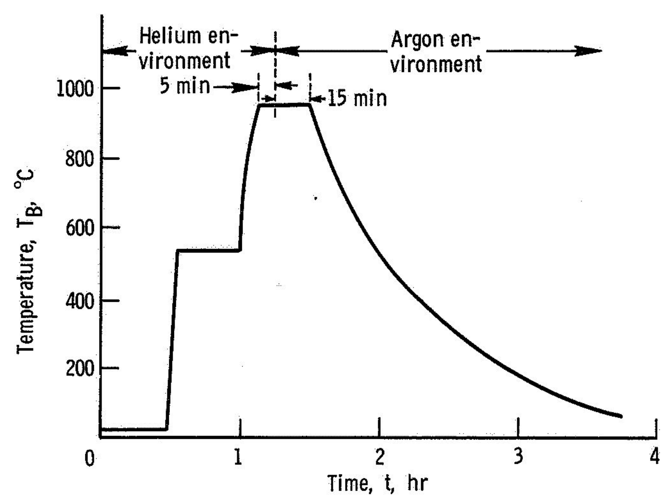

Figure 10. - Temperature-time-environment sequence for fusing powdered glass coatings on a composite accelerator grid.

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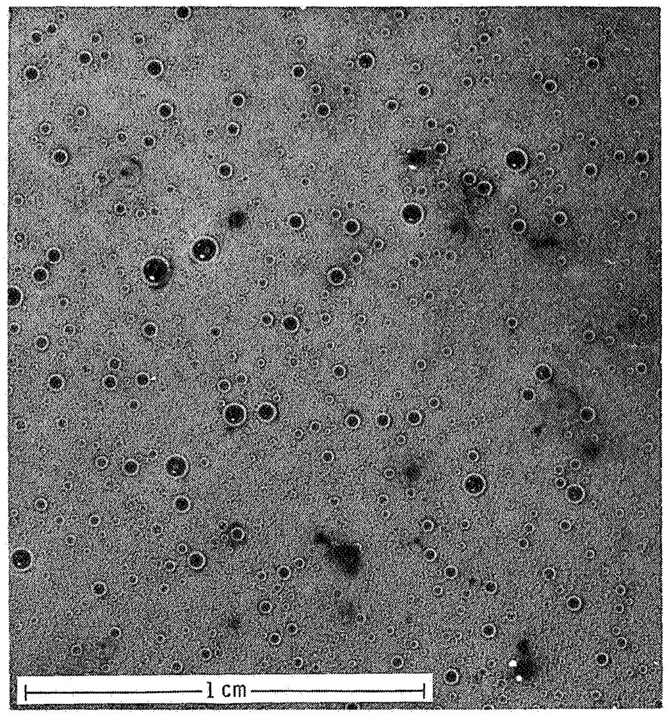
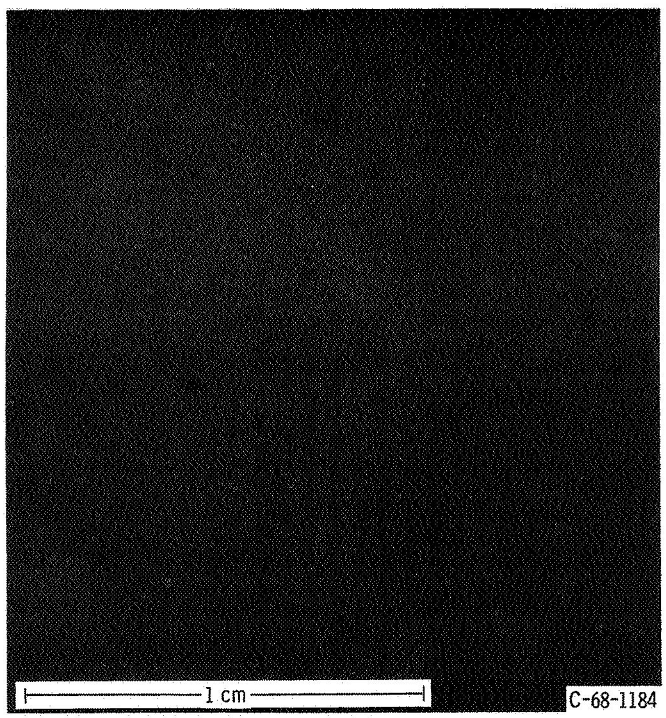


(a) Coating fused in an argon atmosphere resulting in a negligible amount of bubble collapse.



(b) Coating fused using the helium diffusion process. The dark appearance is because the glass is nearly bubble free.

Figure 11. - Photographs of 0.2 mm thick fused Corning glass code 7052 coatings on molybdenum.

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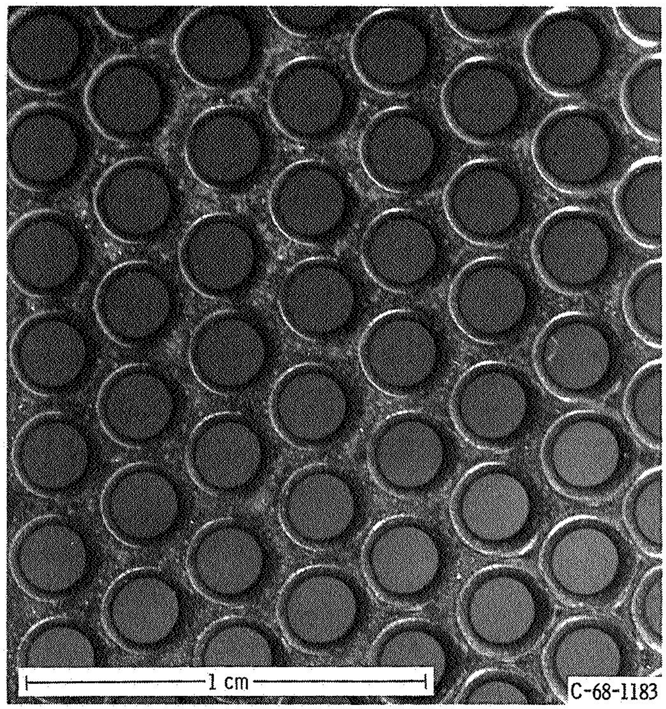

Figure 12. - Photograph of the central portion of the glass coated side of a composite accelerator grid after more than 200 hours operation in a 5 cm diameter thruster. The maximum thickness of the glass is 0.0465 cm.

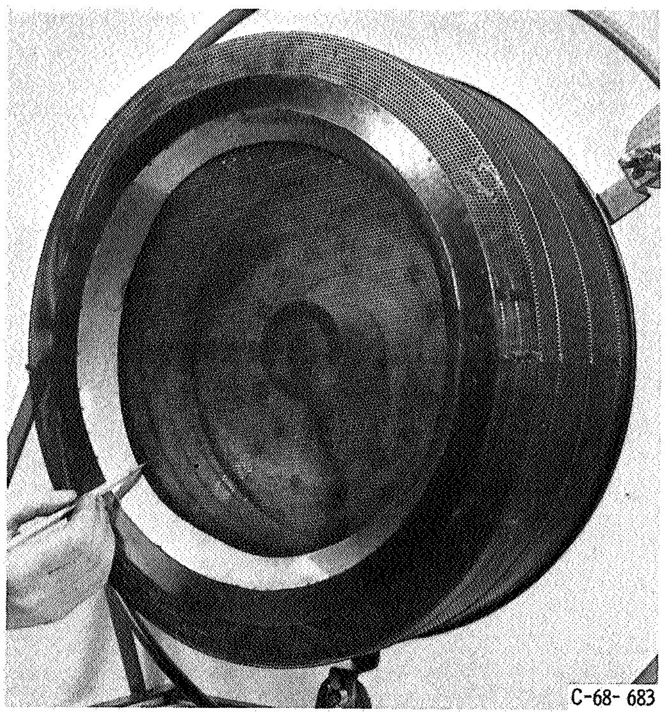

Figure 13. - Fused glass composite accelerator grid mounted on a 30 cm diameter Kaufman thruster.

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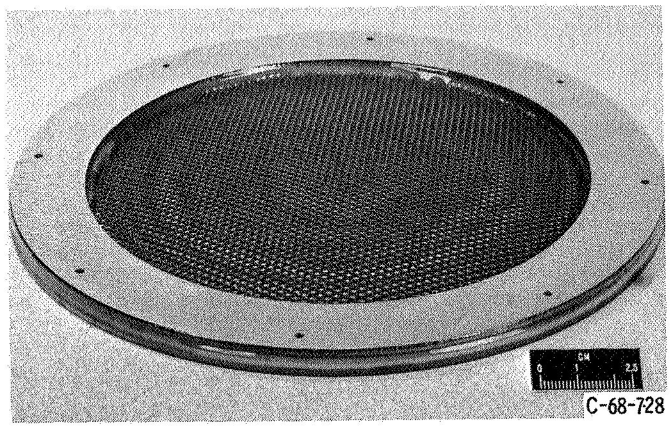

Figure 14. - Dished fused glass composite grid with integral electrically isolated retaining assembly.

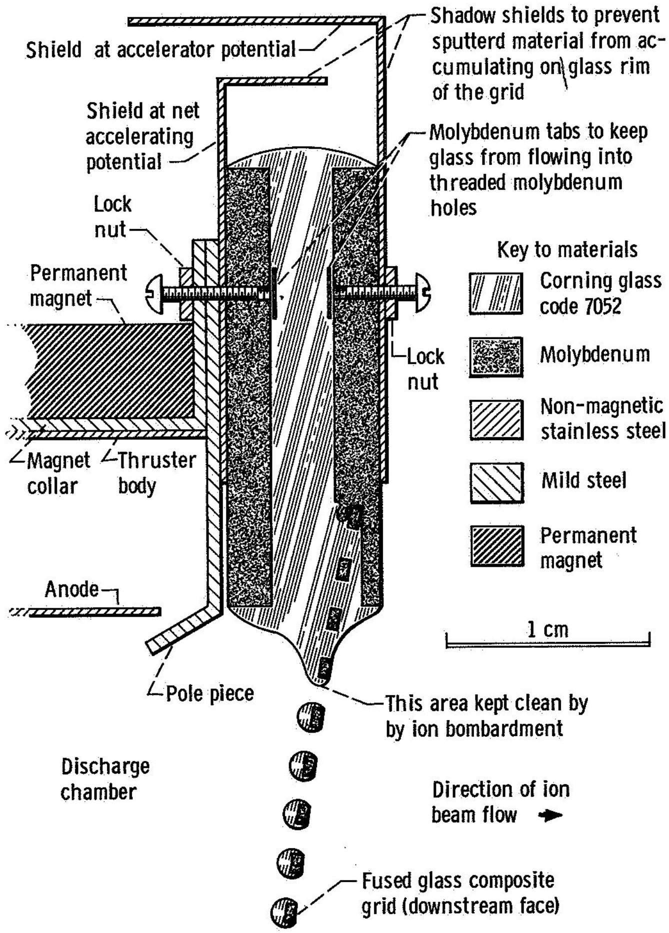

Figure 15. - Section view of the retaining assembly of the dished grid showing thruster mounting detail.