Notes

Fabrication of Porous Tungsten Ionizers by Means of Vapor Plating

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The feasibility has been demonstrated of an original method of constructing the porous tungsten ionizer-manifold assembly used to ionize cesium for ion propulsion. It is accomplished by fabricating a tungsten manifold directly on, and integral with, the porous tungsten. The manifold is produced by vapor plating a nonporous tungsten film from a gaseous tungsten compound.

1. Basic Technique

THE method of producing a copious ion beam for ion propulsion which has received the most attention is known as contact ionization.[1] In practice, it usually consists of passing cesium vapor through a piece of porous tungsten at around 1500°K. The energy levels available to electrons are such that most of the cesium atoms leaving the porous tungsten are ionized.

This technique requires that the porous tungsten be mounted in a leakproof manner on a manifold that brings the cesium to it. Fastening the porous tungsten to the manifold by conventional techniques, usually brazing, has proved very difficult. Therefore, the following ionizer fabrication technique has been investigated.

The porous tungsten is mounted on a mold that has the shape desired for the manifold. A layer of tungsten is plated over the porous tungsten and mandrel. Finally, the mandrel and the tungsten plated over the emitting surface are removed. These general objectives allow considerable variation in practice. Three specific techniques are described below, all having been shown to be feasible.

The tungsten manifold was deposited by means of vapor plating. Vapor plating should not be confused with vacuum deposition. In the latter, case, the pure metal is introduced into the system, raised to a temperature sufficient to vaporize it, and condensed on a cold specimen. However, in vapor plating, the metal is introduced in the form of a volatile compound, and the temperature of the specimen is elevated. The specimen is surrounded by the vapor of the metallic compound, often mixed with other gases. A chemical reaction between the vapor molecules which deposits the desired metal or compound takes place at the surface of the specimen. Tungsten has been vapor plated† by pyrolysis or hydrogen reduction of WCl_6,[2] pyrolysis of $W(CO)_6$,[3, 4] and hydrogen reduction of WF_6.[5, 6] The WF_6 process is the most popular for a number of reasons, but an inexperienced laboratory might prefer to try the high temperature $W(CO)_6$ process,[4] which is the easiest and least critical to set up.

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† Tungsten and other materials are vapor plated commercially by San Fernando Laboratories, Pacoima, Calif.

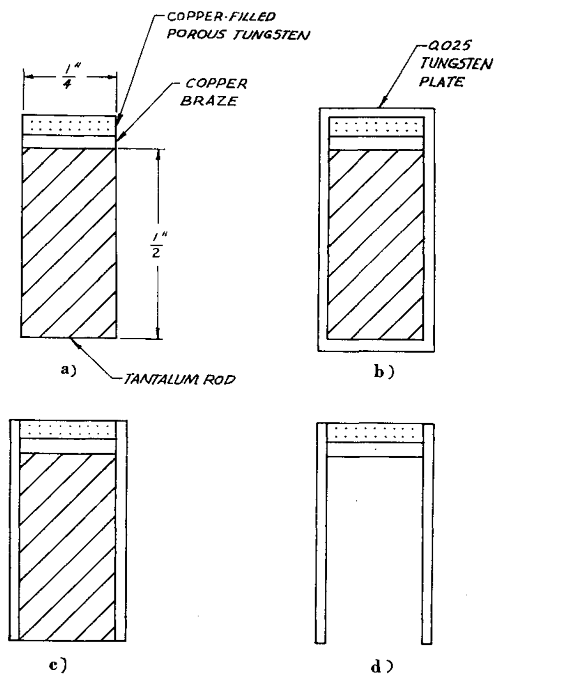

Fig. 1 Method used to construct porous tungsten ionizer

2. Copper-Filled Disc, Brazed to Mandrel

A simple ionizer has been constructed using the steps shown in Fig. 1:

a) A copper-filled porous tungsten disc of $\frac{1}{4}$-in. diam and 0.020-in. thickness was brazed to a $\frac{1}{4}$-in. tantalum rod with copper. The face and edge of the disc were sandpapered to remove a layer of copper which may have existed on them, so that the tungsten to be plated would bond directly to the porous tungsten.

b) A gas-tight layer of tungsten, 0.025-in. thick, was vapor plated over the porous tungsten disc and tantalum mandrel by means of WF_6 reduction.

c) The tungsten plate was ground off the top of the porous tungsten disc and the bottom of the tantalum rod.

d) Hydrofluoric acid was used to dissolve the tantalum.

e) The copper was removed from the porous tungsten, along with the brazed layer, by heating in a vacuum. Copper had been chosen for its tasks because it does not alloy with tungsten and therefore can be removed in this way.

In constructing this sample ionizer, a crack appeared in the porous tungsten during heating to remove the copper. It has been shown that the use of temperature-stabilized porous tungsten eliminates this difficulty (next section).

This technique is adapted easily to the manufacture of a multiple array of small ion emitters. A single, large, copper-filled, porous, tungsten disc, the size of the whole array, would be used. After being plated with tungsten, only the areas to emit ions would be uncovered by grinding and/or machining. The remainder of the tungsten plate on the face of the disc would mask the areas that are not to emit ions. The proposed procedure is shown in Fig. 2.

3. Copper-Filled Disc, Unbrazed to Mandrel

It is of interest to know if an ionizer can be constructed in the manner of the previous subsection except for omitting the brazing operation. The problem here is that tungsten may be plated between the mandrel and the porous tungsten disc and thereby prevent cesium from passing from the manifold into the porous tungsten.

A sample ionizer has been constructed in this way with approximately the same dimensions as previously mentioned. Since brazing was not required, it was possible to use a stainless-steel mandrel, which was found to slip out of the plated

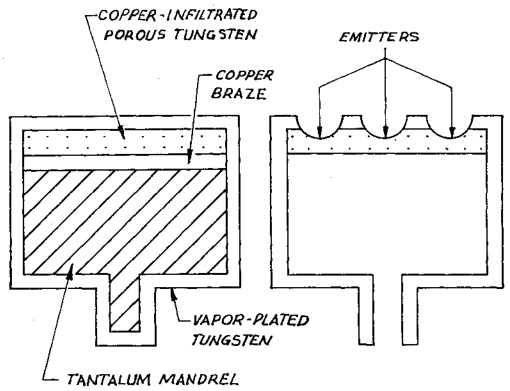

Fig. 2 Proposed construction of an array of small ion emitters

manifold easily after removing the plate from the bottom of the mandrel.

This procedure has the requirement that during the plating operation the tungsten deposit must bridge the gap between the disc and the mandrel in order to form a continuous manifold. Only hydrogen reduction of WF_6 was successful in this task. In order to aid in bridging the gap, a tungsten wire was wrapped around the bottom of the mandrel and given the shape of a fishhook in order to apply pressure against the top of the disc, pressing it against the mandrel.

After removing the stainless mandrel, the ionizer was inverted and filled with sodium hydroxide solution. The inside face of the porous tungsten disc was milled electrochemically a bit, in case it had been covered during the plating operation. The results described in the next section indicate that this was unnecessary if sufficient pressure were applied to hold the disc and mandrel together. After boiling out the copper, the ionizer was found to be porous.

In this case temperature-stabilized porous tungsten‡ was used, which did not crack during heating to remove copper. A flawless ionizer, shown in Fig. 3, resulted. It has been milled electrochemically slightly, as this process polishes the plated tungsten and pits the porous tungsten, thus allowing them to be distinguished visually.

4. Unfilled Disc, Unbrazed to Mandrel

If one were to construct an ionizer starting with porous tungsten that had not been filled with copper, it would be necessary to mask its front face because tungsten plated over the front of the ionizer could not be ground off without closing the pores. The feasibility of this approach has been verified as follows. An unfilled disc of $\frac{1}{4}$-in. diam was placed between two $\frac{1}{4}$-in. steel rods that were held together by tight springs of tungsten wire; after plating the assembly with tungsten, the porous tungsten disc was found still to be permeable to gas.

5. Tests

The porosity of the ionizers was verified by forcing hydrogen through them while immersed in water.

The vapor plated tungsten was found to adhere to unfilled porous tungsten with a strength of about 2500 psi. The adhesion of plated tungsten to copper-filled porous tungsten is believed to exceed the strength of the porous tungsten if its surface is clean of copper, because thermal stress caused the porous tungsten of the first ionizer to crack rather than to separate from the plate.

A tungsten plate 2-mil thick has been found to hold a vacuum of $5(10)^{-3}$ mm, and another of 5-mil thickness held $3(10)^{-5}$ mm, the limit of the vacuum system used.

‡ Temperature-stabilized porous tungsten was supplied by Phillips Metalonics, Mt. Vernon, N. Y.

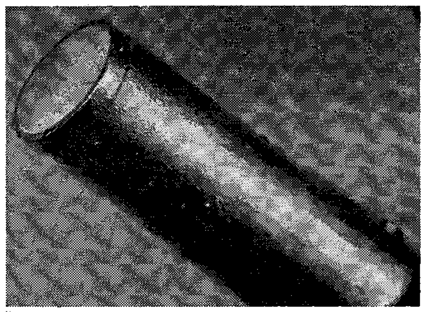

Fig. 3 Porous tungsten ionizer

6. Miscellaneous Techniques

Tungsten can be milled electrochemically by making it the anode in a NaOH solution.[7–9] Any metal that is not amphoteric is suitable for the cathode. Tungsten is dissolved readily in this manner, but most other metals are not affected, including stainless steel, copper, and tantalum. If copper-filled porous tungsten is milled electrochemically the copper is exposed, the tungsten being dissolved out to a depth a little below the surface of the copper, providing an effective method for detecting copper in porous tungsten. Solid tungsten may be polished in this way. The optimum solution strength was found to be 3% and the optimum applied voltage to be just below the onset of bubble formation at the anode. Porous tungsten is roughened by this procedure. However, it may be possible to grind porous tungsten to a desired shape, thereby closing the pores on the surface, and then to remove electrochemically a thin film from the surface in order to reopen the pores.

Although copper adheres readily to tungsten, copper brazing to tantalum is difficult. Cleanliness and a hydrogen atmosphere are required. Copper brazing to stainless steel is performed readily, but care is required to prevent raising the temperature too high if it is desired to remove the copper later. Otherwise the copper and stainless steel form a eutectic that alloys with the tungsten.

The ionizer of Sec. 2 used a 0.020-in. thick copper-infiltrated porous tungsten disc. The copper was removed in 2 hr. at 2000°C. The porous tungsten disc of the ionizer of Sec. 3 was 0.050-in. thick and required 8 hr to purge at 1850°C. Two suppliers have stated that copper cannot be removed completely from porous tungsten of greater than 0.060-in. thickness.

References

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