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FINAL CONTRACT REPORT

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Controlled Thermonuclear Research Division
Washington, D.C.

Research on
POROUS IONIZERS AS IMPROVED PLASMA SOURCES

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ABSTRACT

The final report consists of an exposition of work performed in developing porous ionizers as improved plasma sources plus copies of articles submitted for journal publication under the contract.

Although the construction of successful emitters has proved very difficult, the development problems have been solved and it appears feasible to construct successful units based on the fabrication techniques developed under this contract. A detailed description of the final unit completed under this contract is included.

Papers submitted for publication and completed under this contract are attached. They are as follows:

- (1) C. Forbes Dewey, Jr., "Applications of Lasers to Line Spectroscopy", submitted to J. Quant. Spectros. and Radiative Transfer.
- (2) C. Forbes Dewey, Jr., "A New Technique for Joining Porous Refractory Metals", accepted for publication by AIAA Journal.
- (3) C. Forbes Dewey, Jr. and Peter E. Göttinger, "Volume Ionization via Laser Radiation in a Cesium Plasma Diode", submitted to J. Appl. Phys.

1. POROUS IONIZER DEVELOPMENT

A. Design Considerations

The concept of porous ionizers as improved plasma sources was originally proposed by the principal investigator in 1967¹. The development of this device which ensued during the present contract has proved that it is possible to construct a suitable unit delivering controlled amounts of cesium to a porous emitter of 2.5 cm diameter and operating at a temperature of at least 2400°K.

Our design is shown schematically in Fig. 1. The emitter is radiatively heated by a hot refractory metal plate, which in turn is heated by electron bombardment. Proper control of the bombardment current to the heater plate allows precise control of the temperature distribution across the radiator ... and hence across the face of the emitter. The emitter button is supported by a thin tantalum shell and conduction losses are negligible. The design shown in Fig. 1 allows the support shell to operate at a considerably lower temperature than the emitter.

It is imperative that the annular space between the emitter and radiator shells be leak-free to avoid cesium emission at points other than the porous emitter itself. In our design, this was accomplished by laser welding all components together into a continuous structure. The particularly difficult job of joining the emitter shell to the emitter was accomplished by using an intermediate layer of vapor-deposited tantalum. The details of this procedure are given in Ref. 2 (copy attached).

The upper temperature limit of the emitter is determined by the evaporation of atoms from the surface of the radiator, and subsequent deposit on the surface of the porous emitter which plugs the matrix. In our design, we were not able to achieve a tungsten-tantalum weld which would not fail at high temperature, and hence we were limited to using a tantalum radiator. In one assumes the useful life of the porous emitter will be 100 hours of operation, and that the termination of successful operation will be coincident with the deposition of 10 microns of evaporated material from a tantalum radiator³, then the maximum allowable radiator temperature becomes $T_{\text{RADIATOR}}^{(\text{max})} \approx 2700^\circ\text{K}$ and the corresponding emitter temperature is approximately 2100°K . The corresponding limit for a tungsten radiator is roughly 100°K higher, and for each increase of a factor of ten in the allowable evaporation rate, the corresponding emitter temperature increases by approximately 150°K .

The preceding calculation is based on the following assumptions:

- (1) No additional heat shielding is provided; the button radiates to a cold black body. If one used a modest amount of shielding (e.g. the Frascati design), the emitter temperature, for a fixed radiator temperature, would be $200\text{--}400^\circ\text{K}$ higher.
- (2) The limit of 10 microns may be somewhat conservative. For a porous matrix of ~ 40 micron pore diameter, severe plugging would probably not occur until the deposited layer was on the order of the pore size.

In designing the pressed tantalum shell support structure, we encountered some difficulty in deep-drawing the shells without wrinkling. Although some experience is necessary to master this technique, we found it quite reproducible after a little experimentation. Fig. 2 is a self-explanatory photographic history of this manufacturing technique. An unlimited number of shells can be rapidly formed with the same die. The material costs run around \$150 per assembly, exclusive of the porous button.

Choice of the 30% tantalum - 70% tungsten alloy for the button was dictated by the requirement that the porous material not sinter together during extended operation at 2300°K and above. Pure tungsten or pure tantalum exhibit rapid sintering at these temperatures. The advantage of the W - Ta alloy are described in Ref. 5, a copy of which is enclosed. It is believed, on the basis of our experience, that an 80% Ta - 20% W alloy would have been a better choice from the standpoint of resistance to thermal stresses and compatibility with the tantalum vapor-deposited coating which was used to provide the weld ring for attachment to the tantalum shell. Much to our dismay, we found that the materials development problems, and the attendant cost in terms of dollars and time, ate up a very large fraction of our contract. We believe that these were substantially solved during the contract, and the principal investigator would be very happy to provide additional details on our procedures and results to anyone who wishes to pursue the development of the ionizers.

B. Operating Results

Three emitters were completed during the contract. One of these was totally successful and operated very satisfactorily up to about 2450°K. The other two exhibited small leaks because of improper welding procedures (we learned on these first two) but were satisfactory in other aspects of their performance. Time did not permit the proper sealing of these units by additional welding.

A block diagram of the electrical power system used to heat the buttons is given in Fig. 3. Fig. 4 presents the final filament design, constructed to give a slightly higher current emission at the outer edge of the button than in the center in order to achieve a uniform emitter temperature. Using photoresistive patterns (matching patterns on both sides) and acid etching, it was possible to investigate quickly and easily a variety of geometries for specific emission characteristics.

Although the filament design technique and fabrication was very successful, the filaments were not. Out-of-plane-sagging and warping occurred which tended to bring one or another part of the filament into closer proximity to the target anode (the radiator button). Because we operated the filament somewhere between space-charge-limited and emission-limited, the distortion of the filament-anode gap caused hot-spots to appear on the anode (radiator) and subsequently on the emitter button itself. This was dramatically demonstrated when we turned on the Q-machine magnet to 2 kilogauss and promptly blasted a hole through both the anode shell and the button shell; we produced a beautiful electron-beam drilling machine!

In retrospect, it was pretty silly not to forego the clean, low-current filament design in favor of a less aesthetic, rugged, high-current low voltage filament operating emission limited. As Nathan Rynn once said to me over a glass of beer, power supplies are cheaper than development time.

Fig. 5 presents a clear view of the final emitter and cesium oven as produced during this contract. Fig. 5(a) is a rear view of the emitter assembly showing the heavy tantalum base, the tantalum anode (radiator), the molybdenum mounting plate screwed to the emitter, and the tantalum tube leading to the cesium oven. Fig. 5(b) is a top view showing the porous button and its support shell; not easily visible is the delicate laser weld between the shell and the tantalum-coated button. Parts (b) and (c) of Fig. 5 show the cesium oven welded to the emitter and ready for service in the Q-machine.

In anticipation of early success with our emitter, we had gone ahead in parallel to produce a very versatile, zero problem support for our entire emitter unit. The cesium was housed in a small oven cantilevered directly from the emitter. The emitter in turn was "flown" free in the center of the vacuum envelope on the end of a U-frame support. The emitter position was adjustable in 3 directions (vertical, horizontal, and axial) during operation of the Q-machine. The emitter support was cantilevered from a bellows-sealed end plate whose position was controlled by two micrometers and an adjustable swivel support. The arrangement is clarified in the photographs appearing as Fig. 6. Visible in the upper right-hand photograph is

the photo-etched cathode and heat shield assembly; the emitter-oven unit screws directly to the end of the support-rail through the two holes visible in Fig. 5(a). Note the 9 current feedthroughs incorporated in the baseplate assembly. The diameter of the entire support assembly, including a metal O-ring sealing flange, was about 5 inches.

Operation of the entire assembly was only achieved during the last several weeks of the contract. Fig. 7 describes the test system. We compiled some 36 hours of operating time with the leak-tight emitter during which pyrometric scans were made of the emitter temperature distribution, filament and high-voltage power were correlated with emitter temperature, outgassing and filament evaporation problems were investigated, and the operation of the adjustable emitter support system was checked. The following conclusions were drawn:

(1) The concept of a porous emitter with integral cesium oven was practical and highly successful.

(2) The adjustable emitter support allowed stable, accurate alignment of the emitter position during operation of the Q-machine. Perfect axial and radial placement of the emitter can be achieved in situ without the need for elaborate alignment of the magnetic field, tube axis, and emitter support. The emitter is aligned while at full operating temperature, thus obviating thermal expansion problems.

(3) The present design was arranged to slide down the bore of a 3 1/4" I.D. solenoid, using a 4" O.D. stainless envelope while maintaining a 1" O.D. emitter. This system, with its compact dimensions and small calibre, permitted a very efficient and inexpensive magnet and magnet power supply.

(4) The emitter temperature distribution was highly controllable by (or in more pessimistic terms "sensitive to") changes in the geometry of the filament. Having licked the metallurgical difficulties of construction, this remained the primary limitation. This is a solvable problem. It is reasonable to expect that the emitter temperature distribution, established as it is by the heat flux pattern from the radiator, could be at least as good as any end plate heated by direct bombardment, and probably better inasmuch as the high reflectivity of both the emitter and radiator tend to smooth out variations of the local perpendicular radiation flux.

(5) It was not possible to achieve actual Q-machine operation because of the catastrophic failure which occurred when the magnet was first turned on with the emitter in full operation. Had we had another few months and a few dollars (and a new non-sag, space-charge-limited filament), there would have been no difficulty in achieving positive results.

II. FINAL REMARKS

Of the three papers submitted for publication under this contract, one is two months overdue for its appearance in the AIAA Journal, and the other two are undergoing final revisions, with publication expected in early 1970.

Part of the delay in the publication of these latter two has resulted from an attempt to incorporate additional material into the final versions destined for print. In the case of the Laser Spectroscopy paper, developments in tunable dye lasers during the last year has literally blown this particular branch of spectroscopy "wide open", and it would be inaccurate at this time to publish a review which did not include these important results. (It is my understanding that a dye laser is presently being used in a barium Q-machine at the Plasma Physics Laboratory, Princeton, in the manner described in the Laser Spectroscopy paper.)

The Plasma Enhancement paper by Peter Ottlinger and me has been withheld briefly while we complete at M.I.T. a preliminary set of experiments on pumping a partially-ionized cesium plasma with a tunable dye laser to verify the theory of that paper. As the reader may have already discerned, the theoretical estimates of plasma enhancement and power requirements relative to thermionic converters are somewhat tenuous, and experimental proof would be most useful.

References

1. C. F. Dewey, Jr., "Production of Quiescent Alkali Plasmas using Porous Ionizers", in Vol. II, Proc. Conf. of Physics of Quiescent Plasmas, Laboratory Gas Ionizzati, Frascati, February, 1967, pp 601-616.
2. C. F. Dewey, Jr., "A New Technique for Joining Porous Refractory Metals", AIAA J. (1969), (to appear).
3. Evaporation rates for tantalum are taken from the data of Langmuir and Maier, Phys. Rev., 55, 748 (1939), as requested in W.H. Kohl, Materials and Techniques for Electron Tubes, Reinhold, N.Y., 1960, p 338.
4. Evaporation rate from Table 9.6, p 274 of Kohl (Ref. 3).
5. C. F. Dewey, Jr., and F. R. Adams, "Investigation of the Kirkendall Effect in Porous Alloy Ionizers", in Refractory Metals and Alloys IV: Research and Development, R. I. Jaffee et al. (eds.), Gordon and Breach, New York, 1968, pp 1281-1302.

(A) = LASER WELD IN ARGON ATMOSPHERE

FIG. 1 CROSS-SECTION DRAWING = f Emitter

Figure 2. Manufacture of Emitter Shells

a. Die pressing tantalum sheet

c. Welded and assembled radiator

b. Successive processing of emitter shell (above) and radiator (bottom)

d. Removal of emitter shell from die

A: 0-1 KV, 0-3 AMP, CONSTANT VOLTAGE POWER SUPPLY
 B: 0-15V, 0-30 AMP, FILAMENT SUPPLY
 C: ERROR AMPLIFIER TO DRIVE PASS TRANSISTORS

FIG. 3. HEATING AND BOMBARDMENT CIRCUIT

DIAMETER BETWEEN
 OUTER SUPPORT
 HOLES = 1.20 IN.

MATERIAL : 010 IN. W

PHOTO-RESIST USED TO
 TRANSFER PATTERN TO
 BOTH SIDES, ELECTROLYTIC
 ETCHING TO CUT EXPOSED
 SUBSTRATE.

FIG. 4. FINAL FILAMENT DESIGN

Figure 5. The Final Emitter and Cesium Oven

a. Rear view of emitter assembly

b. Side view of emitter, showing porous button

c. Assembled oven and emitter: rear view

d. Assembled oven and emitter: side view

Figure 6. Four Views of the Emitter Support System

a. External adjustment system

b. View of bellows seal and electrical feedthroughs

c. View of support, electrical feedthroughs, and main flange seal from vacuum side

d. Close-up of bombardment filament and heat shields

Figure 7. Photographs of final test system

- a. Support system and assembled emitter prior to final insertion into the Q-machine.
- b. Q-machine assembly with magnet rolled to left, exposing main vacuum tube. Plumbing to right leads to ion pump and sublimation pump.

a. Support system and assembled emitter

b. Q - machine