SRI International

APPLICATION OF MICROFABRICATION TECHNOLOGY TO THERMIONIC ENERGY CONVERSION

Progress Report 4

Covering the Period 1 May 1980 to 31 July 1980

MASTER

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By: Ivor Brodie, Manager, Physical Electronics Program
Engineering Sciences Laboratory

Prepared for:

U.S. Department of Energy
Division of Fossil Fuel Utilization
20 Massachusetts Avenue, N.W.
Washington, D.C. 20545

Attn: Owen S. Merrill, Mail Stop 4128

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ABSTRACT

In the report period, two applications of microfabrication technology to thermionic converters have been investigated theoretically. The first is a novel method of maintaining micron or submicron spacings over large areas ($> 1 \text{ cm}^2$), using metals of different expansion coefficients to eliminate the shear stresses on the insulating pillars separating the electrodes. The second uses low-voltage field-emission sources to create ions in a large ($\sim 1 \text{ mm}$) interelectrode gap for space charge neutralization. The theoretical results for both these approaches are highly encouraging. A new person has been employed to carry out the experimental investigations and will begin to fabricate and test experimental devices in the next quarter.

A paper reporting our progress to date was presented at the 1980 IEEE International Conference on Plasma Science on 21 May 1980.

I INTRODUCTION

This is the fourth progress report in a theoretical and experimental program to evaluate those areas where three-dimensional microfabrication techniques could be important to improving methods of thermionic energy conversion. SRI International (SRI) is conducting the program for the Division of Fossil Fuel Utilization, Department of Energy (DOE) under Contract No. DE-AC02-79ET15423.

The scope of work encompasses a three-year level-of-effort program to evaluate the significance of application of ultramicrofabrication techniques to thermionic energy conversion. To this end, the following specific steps will be attempted.

- Step 1--Prepare structured electrodes
- Step 2--Build and evaluate a submicron close-spaced diode
- Step 3--Study field-ion injection for space-charge neutralization.
- Step 4--Conduct microfabrication service for programs in the thermionic energy conversion field.

The second year's effort is directed mainly toward Step 2, with some effort applied to Step 3. This report covers the period 1 May 1980 through 31 July 1980.

II PROGRESS DURING THE REPORTING PERIOD

The effort in the period covered by this report has been directed toward evaluating concepts for two novel diode structures. The two formidable problems that must be solved in a microstructure vacuum diode design are

- Maintenance of close spacing over large areas
- Relief of stresses induced by differential thermal expansion in the diode electrodes.

In previous reports we discussed several possibilities for accomplishing this goal. These have evolved in the report period into a scheme as illustrated in Figure 1. The emitter is made of pure tungsten or molybdenum, whose work function will be controlled by the cesium vapor pressure maintained in the gap. The collector will be made of a cesium-compatible material, whose expansion coefficient is such that there is no relative movement between it and the emitter when both are heated from room temperature to their respective temperatures of operation. For this

SECTION VIEW

TOP VIEW

FIGURE 1 PROPOSED STRUCTURE

Expansion coefficient of the collector material is such that there is no net differential expansion relative to the emitter material between room temperature and the respective electrode operating temperatures.

we assume, as previously, $T_E = 1650^\circ\text{K}$, $T_C = 700^\circ\text{K}$, values compatible with the topping of a fossile fuel power station. The insulator will be aluminum oxide, which is known to be cesium-compatible at these temperatures. An attractive collector material has proved to be copper. Knowing the expansion characteristics of tungsten or molybdenum, and copper, we have plotted [Figure 2] T_E versus T_C such that the relative expansion between the two electrodes is zero. Thus, for $T_E = 1650^\circ\text{K}$, T_C must be 745°K , and 665°K for emitter electrodes of molybdenum and tungsten, respectively. These are close to the chosen value of 700°K . During warm-up as T_E is increased, T_C should be held at the corresponding values given by Figure 2 to maintain zero relative expansion between the electrodes. Copper is attractive for other reasons than expansion match:

FIGURE 2 TEMPERATURES AT WHICH EMITTER AND COLLECTOR TEMPERATURES ARE SUCH THAT THE ELECTRODES HAVE SIMILAR EXPANSIONS WHEN HEATED FROM ROOM TEMPERATURE ($\sim 300^\circ\text{K}$)

- Readily deposited by evaporation.
- Cesium-compatibility at collector temperatures.
- Very low vapor pressure at the collector operating temperature ($\sim 10^{-14}$ torr).
- Physically soft and yielding, can accommodate shear stresses even when perfect expansion matching is not always obtained.
- High electrical and thermal conductivities.

We propose to fabricate a diode by the following method (Figure 3).

Step 1: A disc of molybdenum (or tungsten) 1 cm diameter will be polished to a smoothness of substantially less than 1 μm . Note that flatness is not so essential to this technique as is smoothness.

Step 2: A film of aluminum oxide 1 μm thick will be evaporated on the smooth surface.

Step 3: A film of copper a few micrometers thick will be evaporated over the oxide film.

Step 4: An electron beam resist will be spun on the surface, and holes produced in the resist by the usual methods. The copper will then be etched away, leaving a corresponding array of holes in the copper layer.

Step 5: An etch that attacks aluminum oxide, but not copper or molybdenum, will be used to etch the oxide layer. Etching will be continued until only diamond-shaped pillars of oxide remain between the holes. The cross-sectional area of the pillar will be small compared with the exposed area of the electrodes.

We will then be left with the structure shown in Figure 1. Although the details of the hole sizes and spacing have yet to be fixed, clearly the area covered by the pillars and holes should be small compared to the total electrode areas.

The completed structure will be thermally tested. The holes in the copper will allow cesium vapor to enter the interelectrode gap at a vapor pressure corresponding to the lowest temperature in the system. The work function of the emitter will be controlled by the cesium pressure; the collector will always be cool enough that condensed cesium will determine the work function of the collector surface. Because all the current must travel through the collector, it may have to be made thicker by plating to reduce power loss by Joule heating, and to maintain the good heat conduction necessary for the temperature over the copper electrode to be uniform.

(a) POLISH EMITTER

(b) EVAPORATE 1- μm LAYER OF Al_2O_3

(c) EVAPORATE 5- μm LAYER OF Cu

(d) SPIN ON e-BEAM RESIST. EXPOSE, DEVELOP, AND ETCH AN ARRAY OF 5- μm HOLES. REMOVE RESIST

(e) ETCH Al_2O_3 LEAVING SMALL PILLERS

FIGURE 3 FABRICATION PROCEDURE

The second method analyzed is shown in Figure 4. The spacing between the emitter and collector is now made comfortably large (~ 1 mm) so that the problem of close spacing are avoided. Ions to neutralize the space charge are produced by injection pulses of field-emitted electrons into the gap from holes in the collector as shown. The gas in the gap consists of cesium at the partial pressure necessary to maintain the desired work function on the emitter, plus xenon maintained at a pressure such that the injected electrons will have many ionizing collisions with gas molecules before reaching the emitter. Calculations indicate that the presence of xenon may not be necessary; however, the thickness of the gate/collector film (~ 1 μm) may prove troublesome because of the large currents it must carry. Experimental tests of ionizing efficiency are being planned and further calculations on the operation of this device are being carried out.

III PERCENTAGE TIME SPENT ON CONTRACT

During the report period, a new staff member (Clay Shepherd) has been assigned full time to assist the principal investigator (Dr. Ivor Brodie) and the microfabrication technologist (C.A. Spindt) in accelerating this program. During the report period, Dr. Brodie spent approximately 7 percent of his time on this project.

FIGURE 4 IONIZATION OF GAS IN INTERELECTRODE REGION BY FIELD EMISSION

The substrate is switched from ground (or collector potential) to $-V$ volts such that a current density J (averaged over the array) is injected into the inter-electrode region for a time t_0 .

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