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APPLICATION OF MICROFABRICATION TECHNOLOGY TO THERMIONIC ENERGY CONVERSION

Progress Report 5

Covering the Period 1 August 1980 to 31 October 1980

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MASTER

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ABSTRACT

During the report period, considerable effort was directed toward the fabrication of a micron-spaced thermionic converter by the technique proposed in Progress Report 4. In the process, a new technique has evolved which appears more promising and has been investigated theoretically. In both techniques, electrodes of similar differential thermal expansions are utilized to prevent shear stresses from disrupting the spacing pillars. The newer technique has additional advantages that simplify the fabrication of the diode structure, thus making it more practical.

I INTRODUCTION

This is the fifth 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 structure electrode.
- 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 current year's effort is directed mainly toward Step 2. This report covers the period 1 August 1980 through 31 October 1980.

II PROGRESS DURING THE REPORTING PERIOD

The effort in the period covered by this report has been directed toward the experimental and theoretical study of microstructure vacuum diode fabrication methods. The purpose of this study has been to test the feasibility of the fabrication procedure outlined in Progress Report 4, and, through experimentation, to look for possible modifications or alternatives to this procedure.

As proposed, we began with an emitter material consisting of 1/2-inch diameter molybdenum discs which were micropolished by a technique similar to that discussed in Progress Report 2. Initially, we had difficulties in eliminating small pits in the polished surface which can cause pinholes in the aluminum oxide film to be subsequently deposited on this surface. The pits were found to be caused primarily by over-polishing the surface during the final step with the Al_2O_3 polishing compound. As a final preparation of the surface before deposition of a film, we preheated the molybdenum substrate (in vacuo) to accelerate grain growth that might (undesirably) occur during converter operation and to thoroughly clean the surface. The discs were heated to a temperature slightly above the proposed emitter operating temperature of $T_E = 1650^\circ\text{K}$. We had chosen molybdenum rather than tungsten here because our tungsten discs showed large bulk orientation boundaries in addition to grain boundaries after heating. In the future, we propose to use single-crystal materials or polycrystalline materials treated to inhibit grain growth or shifting, such as thoriated tungsten.

We proceeded to evaporate a 1- μm thick film of aluminum oxide (alumina) on the smooth surface. We still encountered problems with some pinholes in the film caused by the unavoidable imperfections in the molybdenum surface and by debris which had collected during and after the deposition and had broken loose. These pinholes are troublesome, as they could cause the copper film electrode evaporation that follows to short to the molybdenum electrode. We attempted to perform multiple evaporations of aluminum oxide after polishing-back the pinholed layer, but this was unsuccessful as the film could not be polished flat enough. The pinholes in the alumina film appeared to be unavoidable.

Nevertheless, the next step--evaporating a thin film of copper--was carried out with the hope that our best effort in polishing the molybdenum and in evaporating alumina would yield a diode structure free of shorts--or one with shorts over a small area that could potentially be etched away later when the array of aluminum oxide pillars are formed. The resulting thin film configuration consisted of copper on aluminum oxide on molybdenum (Figure 1).

FIGURE 1 THIN FILM CONFIGURATION

Magnification 35x; $\sim 1\text{-}\mu\text{m}$ thick copper on $1\text{-}\mu\text{m}$ thick aluminum oxide on a molybdenum substrate.

An electrical test performed on two of the completed structures yielded resistance measurements of about $0.5\ \Omega$ and $20\ \Omega$, which is indicative of significant shorting of the electrodes.

In view of these fabrication limitations and the anticipated difficulty in etching the pillar array, a new technique was proposed: A two-piece diode structure consisting of separate electrodes (molybdenum or tungsten and copper, as before) between which an insulator configuration will be evaporated directly through a mask. By this scheme, the copper collector will continue to give the advantages presented in Progress Report 4, but the copper can be made thicker to accommodate the Joule heating and to maintain good heat conduction necessary for uniform temperature distribution throughout the collector. The soft and yielding nature of the copper is also utilized in this diode fabrication technique. While setting aside the idea of etching through copper and alumina films we plan to pursue this new technique.

The planned diode configuration consists of a "top-hat" shaped emitter (Figure 2) with three (or more) equilaterally spaced holes in the rim to accommodate sapphire/ruby spheres. These spheres will act to support the copper collector in order to help maintain the micron spacing and to facilitate future realignments of the collector.

FIGURE 2 **EMITTER CONFIGURATION**
 The ruby spheres act to support and align the copper collector.

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

- Step 1: A disc of molybdenum (or tungsten) 1/2-inch in diameter will be micropolished to smoothness and machined into the proposed emitter configuration.
- Step 2: A film of aluminum oxide 1- μ m thick will be evaporated on the polished surface. Then, sapphire/ruby spheres (~ 1/16-inch diameter) will be placed in the emitter structure holes.
- Step 3: A disc of polished copper 1/2-inch in diameter will be aligned and hydraulically pressed onto the emitter structure until it yields and forms itself over the inherently convex polished emitter surface and the ruby spheres.
- Step 4: The emitter structure and the collector will be separated, and the aluminum oxide film will be removed from the emitter surface.
- Step 5: A 1- μ m thick aluminum oxide pillar array will be evaporated on the emitter surface; then, the copper collector will be realigned on the emitter and its supports and held in place by some manner.

The completed structure will be a diode with a uniform 1- μ m spacing over the entire emitter area. The exact pillar arrangement has not yet been determined, but the array will maximize emission area while giving sufficient collector support.

The device will then be thermally tested as originally proposed, utilizing the matched expansion coefficients of molybdenum or tungsten and copper.

Initial tests have already been done on the "pressability" of copper upon molybdenum and tungsten, and the results have been very encouraging.

(a) POLISH AND MACHINE EMITTER CONFIGURATION

(b) EVAPORATE Al_2O_3 FILM AND PLACE SAPPHIRE/RUBY SPHERES

(c) HYDRAULICALLY PRESS COPPER COLLECTOR ONTO EMITTER STRUCTURE

(d) SEPARATE ELECTRODES AND REMOVE Al_2O_3 FILM

(e) EVAPORATE PILLAR ARRAY AND REPLACE COLLECTOR ON EMITTER

FIGURE 3 FABRICATION PROCEDURE

III PERCENTAGE OF TIME SPENT ON CONTRACT

During the report period, the principal investigator, Dr. Ivor Brodie, spent approximately 8 percent of his time on this project; microfabrication technologist, C.A. Spindt, about 6 percent; and staff member Clay Shepherd approximately 66 percent of his time.