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Report No. TE4233/4237-110-78

NASA/DOE
ADVANCED THERMIONIC
TECHNOLOGY PROGRAM
PROGRESS REPORT NO. 31

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I. SURFACE STUDIES

A. SURFACE CHARACTERIZATION CHAMBER

No work was performed on this task during this reporting period.

II. PLASMA STUDIES

A. CONVERTER THEORY

The computer program was modified to run the constant electron and ion temperature cases. Direct comparisons were made between these numerical solutions for a constant temperature approximation with those generated for spatially dependent temperatures. It is well known that the analytical formulation for constant temperature is an eigenvalue problem. The permissible eigenvalues limit the range of solutions. The numerical solution with spatially dependent temperatures were found to result in much lower current ratios (J/J_S) than obtained for a constant temperature.

B. EXPERIMENTAL PLASMA ANALYSES

Comparison of the spectrally-resolved lines from a cesium lamp confirmed that the transitions observed in the diode discharges occur solely in cesium. Furthermore, comparison of the higher-order lines observed in the diode plasmas with those in the lamp indicate a greater degree of atomic excitation in the converter. The increased populations are in accordance with the higher electron temperatures created by currents substantially larger (factors of 5 to 10) than those that flow in the lamp.

An initial spectral scan was made of the cesium plasma in a converter operating with a lanthanum emitter. The object of this experiment was to measure transitions associated with pure lanthanum or one of its compounds. No such lines were seen at an emitter temperature of approximately 1000 K. The emitter temperature will

be raised in steps to determine the relationship between temperature and radiation intensity of such lines as well as evidence of impurities in the interelectrode space.

C. ENHANCED MODE CONVERSION EXPERIMENTS

Previously, experiments using $0.05\text{ }\mu\text{m Al}_2\text{O}_3$ particles have achieved $3.3\text{ }\mu\text{m}$ interelectrode spacings between 2.54-cm diameter metallic laser mirrors. These spacings, measured at room temperature using a capacitance technique, were difficult to obtain and highly unstable. The approximate $3\text{ }\mu\text{m}$ lower spacing limit was attributed to dust particles interspersed in the oxide. Even though dust can be eliminated by careful cleaning in a controlled atmosphere, a major problem in these tests may be a wedge effect between the two electrodes. Simple calculations have shown that 0.08 degree non-parallelism can account for the observed step change from $3\text{ }\mu\text{m}$ separation to metallic contact.

The use of uniformly high columns as spacers is being evaluated. Eight 0.5 mm diameter columns of Al_2O_3 were vapor deposited onto a 2.54-cm diameter metal electrode finished to a surface roughness of better than 16 micro-inches. The columns were configured in a circular arrangement near the periphery of the electrode. Good adhesion between column and surface will allow better dust removal from the electrodes. Although Dektak measurements indicated a column height of approximately $1\text{ }\mu\text{m}$, capacitive measurements gave readings over eight times higher. This inconsistency is being investigated. Calculations based on previous heat transfer experiments suggest that the thermal contact resistance between the oxide columns and the metallic electrode surfaces may be sufficient to limit thermal conduction from emitter to collector to practical values.

III. CONVERTER DEVELOPMENT

A. LOW TEMPERATURE CONVERSION EXPERIMENTS

1. Inconel 671 Emitter, Nickel Collector (Converter No. 186).

The performance of this converter was measured at emitter temperatures of 1300, 1400 and 1500 K. First, the collector temperature was optimized at each emitter temperature. Then cesium families were taken at interelectrode spacings of 0.25, 0.5 and 1 mm. A typical cesium family for this converter is shown in Figure 1. Optimized cesium envelopes at the designated spacings for the emitter temperatures of 1300 K, 1400 K and 1500 K are given in Figures 2, 3 and 4, respectively. The completely optimized converter performance for emitter temperatures of 1300, 1400, and 1500 K is shown in Figure 5. These data correspond to a barrier index of between 2.05 - 2.15 eV. A plot of emitter work function (determined from ignited mode saturation current) versus the ratio of emitter to cesium reservoir temperature is given in Figure 6.

Figure 1. Typical Cesium Family of Current-Voltage Characteristics (Converter No. 186).

Figure 2. Optimized Cesium Envelopes at an Emitter Temperature of 1300K and Interelectrode Spacings of 0.25, 0.5, and 1.0 mm (Converter No. 186).

Figure 3. Optimized Cesium Envelopes at an Emitter Temperature of 1400K and Interelectrode Spacings of 0.25, 0.5 and 1.0 mm (Converter No. 186).

Figure 4. Optimized Cesium Envelopes at an Emitter Temperature of 1500K and Interelectrode Spacings of 0.25, 0.50 and 1.0 (Converter No. 186).

Figure 5. Optimized Converter Performance at Emitter Temperatures of 1300K, 1400K and 1500K (Converter No. 186).

Figure 6. Emitter Work Function versus the Ratio of Emitter Temperature to Cesium Reservoir Temperature (Converter No. 186).

IV. COMPONENT HARDWARE PROGRAM

A. CVD COMPONENT DEVELOPMENT

A leaktight braze between a silicon carbide/graphite/tungsten composite hot shell and a molybdenum fixture has been accomplished (see Figure 7). The copper/nickel braze exhibited excellent wetting to both the tungsten portion of the hot shell and the molybdenum. The brazing arrangement is depicted in Figure 8. The essential features of this fixture are the 0.63-mm (0.025-inch) thickness of its inner sleeve and the 0.076-mm (0.003-inch) clearance (custom-fitted) between the outside diameter of the sleeve and the inside diameter of the hot shell.

Composite shell HS-11 remained crack-free and leaktight throughout a temperature cycle test. The temperature-time profiles of tests 4, 5 and 6 are shown in Figure 9. Tests 1, 2 and 3 were performed at slow heating and cooling rates for which no temperature measurements were made. The durability of this shell is underscored by Test No. 6 in which the RF power was suddenly raised to its maximum limits and just as suddenly turned off. Although the dull grey finish of the shell's exterior had turned to a flat carbon black during the course of these tests (due to vacuum reduction of the silicon carbide) no appreciable change in shell thickness was observed.

B. ALLOY HOT SHELL DEVELOPMENT

Simulated furnace testing continued at a furnace gas temperature of 1573 K. The inside of each shell is evacuated to 10^{-7} torr. Table 1 presents the status of these tests as of February 1, 1978.

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Figure 7. Photograph of Copper/Nickel Braze.

Figure 8. Cross Sectional View of Silicon Carbide/Graphite/Tungsten Hot Shell Brazing Arrangement.

Figure 9. Temperature Cycle Tests of HS-11

TABLE I

SIMULATED FURNACE TESTS
(1 February 1978)

TEST PORT NO.	HOT SHELL	TEST HOURS	COMMENT	DATE OF TEST INITIATION
1	REACTION BONDED SILICON CARBIDE	16, 141	LEAKTIGHT THIS HOT SHELL WAS BRAZED TO A MOLYB- DENUM SLEEVE WITH NICKEL-COPPER	9 April 75
2	KANTHAL A1	14, 554	LEAKTIGHT	25 Aug. 75
3	446 CRES PLASMA ARC SPRAYED WITH NICHROME	1, 928	LEAKTIGHT	31 Oct. 77
4	INCONEL 671	7, 591	LEAKTIGHT	17 Nov. 76
5	446 CRES PLASMA ARC SPRAYED WITH Cr_2O_3	1, 928	LEAKTIGHT	31 Oct. 77
6	-	-	-	-

(Clock Reference - 18, 933)

V. COMBUSTION HEATED THERMIONIC DEVICE

A. MINIATURE FLAME-HEATED DEVICE (CONVERTER NO. 179)

Testing of the miniature thermionic device was continued during this reporting period. An unanswered question is the effect on diode operation of combustion-produced hydrogen permeating through the emitter. Consequently, the device was mounted in a vacuum system so that the emitter could be heated by electron bombardment. Operation in this hydrogen-free system will be compared with data taken previously under combustion conditions. The test plan is to allow the device to be electrically heated for a period of 100 hours. A set of current voltage measurements will then be taken. To date 30 hours of electrical operating time have been accumulated.

B. WORKHORSE DEVICE (CONVERTER NO. 188)

The design of the workhorse device was described in Progress Report No. 30. Initial test data were also given in this report. Combustion testing of the workhorse device continued during January at an emitter temperature of 1400 K. The current-voltage characteristics have remained stable. Accumulated operating time is 1075 hours. This test is continuing.

VI. SYSTEM APPLICATION STUDIES

The draft copy of the report from Stone & Webster Engineering Corporation summarizing the design study for thermionic energy conversion (TEC) topping of fossil fueled plants has been received. The major results are summarized below.

A preferred design configuration of thermionic converter/boiler tube assembly was formulated for thermal coupling of the TECs to the steam cycle. It consists of panels of flat thermionic devices bonded to waterwall and platen boiler tubes with square exterior and circular bore. A conceptual design was developed of a thermionic boiler incorporating the following features:

- The waterwalls are replaced by TEC panels.
- The furnace is a modular 2.46 m x 9.23 m cross-section with staged burners along its height so that maximum combustion temperature (typically 3200 F (2033 K) and short residence time (~ one second) are achieved, consistent with high thermionic device efficiency and low NO_x generation.
- The thermionic converters are so arranged in series - parallel strings that their electrical output is compatible with dc-to-ac conversion equipment. Several fault protection features have been included in this design.

Thermal performance of an 800 MWe conventional power plant and an 800 MWe thermionic topped power plant are compared in Table 2. Preliminary cost estimates indicate that a 800 MWe TEC topped liquified coal-fired plant using an advanced thermionic boiler can be constructed for \$ 618 per KWe (1977 dollars). This estimate was based on the FPC block method of cost accounting and includes a 10 percent interest rate and a 6.5 percent escalation rate during construction. Using solvent refined liquified coal at a levelized cost (assuming a 30-year period) of \$ 4.92 per million Btu and a fixed charge rate of 18 percent, it was shown that the capitalized savings in fuel cost is \$ 217 million and that a total capital savings of \$ 156 per KWe could be achieved by using TEC topping.

TABLE 2

COMPARISON OF POWER PLANTS WITH AND WITHOUT THERMIONICS

	<u>Conventional Plant</u>	<u>Thermionic Topped Plant</u>
Total Plant Power Generation	800 MWe	800 MWe
Steam Plant Power Generation	800 MWe	500 MWe
Thermionics Power Generation	-	300 MWe
Station Heat Rate (Btu/kwhr)	9, 123	7, 235
Thermal Efficiency (%)	37.4	47.2*

* Higher thermal efficiencies are attainable with additional thermionic converters on the superheater and reheater. Additional converters were of questionable cost - effectiveness.