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Prepared By
Thermo Electron Corporation
101 First Avenue
Waltham, Massachusetts 02154

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I. SURFACE STUDIES

A. SURFACE CHARACTERIZATION CHAMBER

Samples from surface characterization and converter experiments were analyzed by Auger spectroscopy. A post-mortem Auger analysis of Converter No. 166 indicated that lanthanum had transferred from the lanthanum hexaboride collector to the tungsten emitter. In addition, carbon, oxygen, sodium, cesium, tungsten, and rhenium were detected on the emitter. The emitter surface had become a dull gray that could be peeled easily with a razor blade. The exposed areas contained no rhenium but did contain a greater amount of lanthanum. The source of rhenium must be the molybdenum-rhenium braze that bonds the emitter to the emitter sleeve. No molybdenum peaks were readily apparent; however, if any weak peaks were present, they could have been dominated by the tungsten spectrum. Rhenium and molybdenum oxides are both known to be volatile, rhenium being considerably more so.

Suprisingly, no rhenium was evident on the collector although carbon, oxygen, nitrogen, sodium, nickel, cesium, lanthanum, and tungsten were detected. The lanthanum and tungsten signals were of comparable strengths. Except for one out of the seven spots analyzed, carbon concentrations were small. Most likely, nickel and sodium were introduced during handling subsequent to the opening of the converter.

The Selenium-Reservoir Converter, No. 173, was dissected and its contents were analyzed. The collector had a dark deposit along the edge of the opening to the selenium reservoir. Auger analysis indicated

this deposit to be elemental selenium. The emitter surface was shiny (like electropolished tungsten) except for a number of small dark specks about 1/2 mm in diameter. The highest concentration of these specks appeared in the "shadow" of the selenium reservoir opening. Auger analysis showed the specks to have a high concentration of selenium. A few of the selenium Auger spectra obtained from various spots on the emitter surface were distorted - indicative of a selenium compound.

The emitter of Converter No. 173 was subjected subsequently to an electron microprobe analysis. An analysis taken over an area about 1 mm² at the center of the emitter surface showed the presence of selenium, tungsten, cesium, and a slight amount of nickel. Figure I-1 shows a portion of this analyzed area magnified 1000 times. The lighter rectangular portion of the island-like structure was found to be cesium, as were the numerous globules; the smoother, open areas were tungsten. The crusty region contained cesium, most likely cesium hydroxide, which dried and cracked under the vacuum environment of the electron microprobe. Thus, the emitter surface is segregated into regions of tungsten, selenium, and cesium (hydroxide). The observed distorted selenium Auger spectra are most likely caused by the complicated surface topography of the sample. These analyses, coupled with the independence of the converter characteristics as a function of selenium reservoir temperature, suggest that a selenium cold spot existed in the diode. A second converter is being constructed in order to continue these investigations.

The results of other Auger analyses are given in subsequent sections of this report.

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Figure I-1. Scanning Electron Photomicrograph of Central Region of the Emitter (Converter No. 173) (Magnified 1000x)

II. PLASMA STUDIES

A. CONVERTER THEORY

Schottky and Coulomb scattering effects were added to the analytical model of the ignited interelectrode plasma. The computer program was improved to accommodate these two effects, with preliminary results plotted in Figure II-1. These calculations indicate that Schottky effects can produce output currents significantly larger than the corresponding saturation currents. Coulomb scattering was found to have the potential of substantially increasing the arc drop.

The required emitter sheath height for the formation of the double sheath can be calculated from a simple sheath model by matching solutions derived from independent analyses of the plasma and emitter sheath, as shown in Figure II-2. The double sheath is seen to be formed at a current ratio of approximately 0.55. This value is consistent with experimental observations, assuming such formation is associated with the knee of the I-V characteristics of diodes, and appears at the current ratios between 0.4 and 0.6.

B. EXPERIMENTAL PLASMA ANALYSES

Spectroscopic analyses of converter plasmas under operating conditions were initiated. Spectra are being taken throughout the 4000 to 9000 Å region. Line width, and relative line and continuum intensity measurements allow determination of electron densities and temperatures, as well as excited state population densities throughout the interelectrode region. Sensitive detection may enable trace constituents (e.g., oxides) to be monitored. Changes in plasma conditions due to variations in T_E , T_C , T_R , electrode spacing, and

Figure II-1. Schottky Effect on Converter Performance

Figure II-2. Formation of Double Valve Sheath

current were observed. Temporal decay of interelectrode conditions in pulsed converters are also being investigated. Preliminary measurements of a converter with a tungsten oxide collector ($T_E = 1425$ K, $T_C = 751$ K, 0.25 torr cesium, and 1-mm electrode spacing) have shown maximum electron densities of $2.8 \times 10^{14} \text{ cm}^{-3}$ and electron temperatures below 3000 K. Relative line intensity measurements indicate progressively less equilibrated excited state population densities with decreasing energy levels.

C. ENHANCED MODE CONVERSION EXPERIMENTS

Refined measurements were performed to determine surface thermal deformation of a molybdenum laser-mirror electrode during heating. The apparatus (see Figure II-3) allowed the splitting of a 1-mm beam from a He-Ne laser into two components and reflecting one from the center of the electrode and the other from its edge. These reflected light beams were observed as two spots on a screen placed approximately 20 m away. Deformation of the electrode surface is measured by the relative motion between these two spots. To first order, this relative motion is independent of the thermal distortion of the sample support structure. In a set of experiments with electrode temperatures ranging up to 1675 K, maximum deformations never exceeded $8 \times 10^{-5} \text{ cm}$. This value is sufficiently low to allow efficient operation of close-spaced diodes.

Figure II-3. Experimental Arrangement for Surface Thermal Deformation Measurement

III. CONVERTER DEVELOPMENT

A. LOW-TEMPERATURE CONVERSION EXPERIMENTS

1. Tungsten Emitter, Sprayed Lanthanum Hexaboride Collector (Converter No. 180)

This variable-spacing device employs a specially guarded collector structure (see Figure III-1) in order to determine more accurately the work function of its sprayed lanthanum hexaboride surface at low current levels. Plots of collector work function versus T_C/T_R constructed from retarding mode data show good correlation with dc back-emission values. Work functions as low as 1.45 eV were obtained at T_C/T_R values between 1.4 and 1.5 from retarding plots (see Figure III-2). Attempts to introduce low-pressure oxygen past the cesium reservoir, in order to reduce the collector work function, have been unsuccessful. Work is currently under way with higher pressures of oxygen.

B. HIGH-EFFICIENCY CONVERSION EXPERIMENTS

1. Tungsten Emitter, Sintered Lanthanum Hexaboride Collector ("Showerhead" Converter No. 166)

Measurements of the effects of oxygen diffusion through the porous LaB_6 collector were continued. Oxygen penetration was observed to initially deignite the converter. Pumping on the back of the porous collector would subsequently reignite it. The saturation current of the converter was always a factor of 2 to 3 greater than prior to the oxygen dose. However, this increased performance would not last more than 20 to 30 minutes. Eventually the converter could not be

Figure III-1. Schematic of Guarded Converter

Figure III-2. Work Function of Sprayed Lanthanum Hexaboride Collector Versus T/T_R

ignited under any conditions, and it was assumed that all the cesium had become oxidized. In fact, when the cesium reservoir was slowly heated up to 1000 K, no ignition was possible; the converter was taken off test and was Auger analyzed.

A new LaB_6 "showerhead" converter is being designed with a window to permit spectroscopic analyses of the oxygen diffusion processes.

2. Lanthanum Hexaboride Emitter, Guarded Nickel Collector

This converter is essentially a repeat of No. 168 with a guarded nickel collector (see Figure III-3). The problem with Converter No. 168 was that the current from the tungsten cup could not be separated from the current from the LaB_6 emitter slug. The guarded collector should alleviate this problem in that the current from the tungsten should flow to the guard, whereas the current from the LaB_6 slug should flow to the collector button. The construction of this converter is nearly completed.

Figure III-3. LaB₆ Emitter, Guarded Nickel Collector Converter

IV. COMPONENT HARDWARE PROGRAM

A. CVD COMPONENT DEVELOPMENT

The first free-standing silicon carbide-graphite-tungsten composite hot shell has been fabricated. This shell, shown in Figure IV-1, measures 9.53 cm in length by 2.54 cm in diameter. The tungsten and graphite layers have uniform thicknesses of 0.02 cm and 0.1 cm, respectively. The silicon carbide outer layer is 0.28 cm thick at the hemispherical end and 0.05 cm throughout the cylindrical portion. Design studies are in progress to determine a method to grow greater thicknesses of silicon carbide at the round end, and to establish a hydrogen purge to the inside of the shell during CVD of the silicon carbide. The hydrogen purge is necessary to maintain the internal tungsten deposit free from trace amounts of silicon carbide.

The temperature and flow rate settings of the tungsten CVD apparatus have, for the time being, become established. Tungsten shells, which are 0.05 cm thick at the open end and 0.04 cm thick at the round end, are now routinely formed after an 85-minute exposure to a 150-SCCM flow of tungsten hexafluoride.

A capability for producing composite hot shells has been demonstrated. The CVD hot shell effort of the component hardware program will now be directed along the lines of establishing routinely reproducible fabrication processes.

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 IV-1 presents the status of these tests as of November 2, 1977. A

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Figure IV-1. Composite CVD Silicon Carbide and Tungsten Emitter Subassembly

TABLE IV-1
SIMULATED FURNACE TESTS
(November 2, 1977)

TEST PORT NO.	HOT SHELL	TEST HOURS	COMMENT	DATE OF TEST INITIATION
1	REACTION BONDED SILICON CARBIDE	14,213	LEAKTIGHT THIS HOT SHELL WAS BRAZED TO A MOLYB-DENUM SLEEVE WITH NICKEL-COPPER	9 April 75
2	KANTHAL A1	12,626	LEAKTIGHT	25 Aug. 75
3	KANTHAL A1	12,492	LEAK OBSERVED REMOVED 31 Oct. 77	9 Sept. 75
4	INCONEL 671	5,663	LEAKTIGHT	17 Nov. 76
5	CHROMIZED STAINLESS STEEL 446	5,172	LEAK OBSERVED	17 Nov. 76
6	KANTHAL A1	2,810	LEAKTIGHT	7 May 77

leak was observed on the Kanthal A-1 sample on October 31, 1977. This shell has been removed from the furnace for failure analysis. Two additional hot shells were placed on test on October 31, 1977. Both of these shells were delivered to Thermo Electron on October 6, 1977 in connection with Subcontract 7070-4190-411-Mod #3. The samples were mounted as follows:

Test Port No. 3: 446 CRES Plasma arc sprayed with nichrome, 0.01 to 0.02 cm thick and diffused for 8 hours at 1367 K in a hydrogen atmosphere.

Test Port No. 5: 446 CRES Plasma arc sprayed with Cr_2O_3 , 0.01 to 0.02 cm thick.

Both samples had 2.54 cm inside diameters, 0.38 cm wall thicknesses and were 20.3 cm long. The end caps were TIG welded. The assembly was stress relieved for one hour at 1256 K and air cooled.

V. COMBUSTION-HEATED THERMIONIC DEVICE

The objective of this task is to design, construct, and test a flame-heated thermionic device for eventual use in combustion-heated panels. The first step in this development will be the construction and flame-heated test of a "miniature device" employing the most promising materials in sizes that are readily available. The next step will be the fabrication of a larger "workhorse device," which will be evaluated in a test furnace that provides combustion parameters similar to those in fossil-fuel powerplants. The data and experience with the miniature and workhorse devices will then be factored into a larger "prototype device."

The design of the miniature device (see Figure V-1) integrates the results of the alloy hot shell development at TRW with the variable-spacing diode tests at Thermo Electron. To date, the most promising material for alloy hot shells is INCONEL 671. This high chromium nickel alloy has shown good stability in short-term tests at TRW and also in a long-term test in the Simulated Furnace Facility at Thermo Electron.

The hot shell dimensions are determined by readily available INCONEL 671 tubing (nominally 2.54 cm in diameter). The effective area of the converter is 2.0 cm^2 and is determined by the maximum diameter of the collector that can be inserted into the emitter hot shell without short-circuiting.

The L605 emitter material was chosen on the basis of the favorable data from the variable spacing Converter No. 143. These data were reported in the Progress Report for August 1976.

Figure V-1. Miniature Flame-Heated Device

In order for the temperature drop through the collector structure to be minimized, a potassium filled heat pipe is used in the collector stem. A cooling fin, and/or an auxiliary heater, may be clamped to the outboard end of the collector for diagnostic testing.

The heat source for heating the emitter of the device will be a gas torch. A propane/air, or propane/oxygen, torch will be used in the initial tests.

Construction of the miniature device is in progress. Test results should be available next month.