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TOPICAL REPORT

THERMIONIC PERFORMANCE OF
CVD TUNGSTEN EMITTERS
WITH
NIOBIUM AND MOLYBDENUM
COLLECTORS

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May 1971

Prepared by
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Prepared for
U. S. Atomic Energy Commission
Space Nuclear Systems Division
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Lester K. Price, AEC Project Manager

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I. INTRODUCTION

There has been considerable interest in vapor-deposited tungsten emitters because of their structural and thermionic properties. An evaluation of the performance of these emitters in combination with various collectors will help to determine the most suitable collector material for thermionic reactor and other power conversion applications.

Three chloride vapor-deposited tungsten emitters were selected as being very similar on the basis of their bare work functions and pole figures. Two of these were installed in variable spacing converters, one with a niobium collector and one with a sublimed molybdenum collector. The third emitter will be used with a $\langle 110 \rangle$ tungsten collector in the near future. This report presents the thermionic performance of these two converters and compares their performance with that of several other converters having $\langle 110 \rangle$ and $\langle 100 \rangle$ tungsten emitters and various collector materials. The converters tested are all similar in design and use the same procedures for processing, outgassing, and cesiating.

II. CONVERTER CONSTRUCTION

The converter is a guard ring variable spacing device which permits incorporation of a variety of collector or emitter electrode materials while maintaining the same basic structure. Figure 1 is a schematic of the converter. The device and its fabrication have been described in detail in Reference 1. Some of its features are: (a) a molybdenum collector and guard substrate providing for brazing-on different active electrode materials; (b) a collector heat choke arrangement providing for heat flux measurements during static testing; and

(c) careful outgassing and cesiating techniques for eliminating the possibility of oxygen contamination.

All converters were checked for contamination after outgassing by measurement of the bare emitter work function and by examination of collector families, as described in Reference 1.

III. EMITTER CHARACTERIZATION

The emitters consist of 20 mils of chloride tungsten vapor-deposited on a 150 mil thick fluoride tungsten substrate. The emitters were machined to final dimensions; blackbody holes were then made by electrical discharge machining. After electropolishing, x-ray diffraction measurements were made, and the emitters were heat treated for 20 hours at 2300°K. Bare work function measurements were performed in a vacuum emission apparatus and the three most similar emitters, chosen on the basis of the similarity of their bare work function measurements and pole figures,* were selected. The pole figures are shown in Figure 2, and typical bare work function data are given in Figure 3. The bare work function values for the three, measured at emitter temperatures from 1800 to 2300°K, were

WD-111	4.98 ± 0.02 eV
WD-112	4.98 ± 0.02 eV
WC ℓ -113	5.00 ± 0.02 eV

The bare work function was also measured after the emitter was installed in the converter. The results were in agreement (within 0.03 eV) with those measured in the vacuum emission apparatus.

* Chloride vapor deposition, electropolishing and x-ray diffraction were performed by Dr. Ling Yang of Gulf General Atomic.

Emitter WD-111 was installed in a converter with a bulk niobium collector, and emitter WD-112 was installed with a collector consisting of sublimed molybdenum ($\langle 110 \rangle$ preferred oriented) on a bulk niobium substrate. The details of the deposition technique are described in Reference 2. Emitter WC ℓ -113 is to be used with a $\langle 110 \rangle$ tungsten collector.

IV. THERMIONIC PERFORMANCE DATA

Cesium families were obtained at optimum collector temperatures for the emitter temperature range of 1600 to 2000°K and the interelectrode spacing range of 1 to 40 mils. Typical data for the WC ℓ -Nb converter at a spacing of 10 mils are shown in Figures 4 to 8, and the cesium optimized envelopes for the other spacings are summarized in Figures 9 to 13. Additional data at other interelectrode spacings are shown in Appendix A. The emitter temperatures indicated represent the temperature at the emitting surface. The output voltage is measured from a voltage tap at the end of the emitter sleeve and requires a correction of 1.5 mV/amp/cm² for conversion to electrode voltage.

In order to check the reproducibility of these converters, one of the converters (WC ℓ -sublimed molybdenum) was disassembled and rebuilt. Typical cesium families before and after rebuilding are shown in Figure 14. Note that the performances of the two converters are in agreement within 20 mV. For example, a current density of 10 amps/cm² is obtained at a voltage of 0.6 volts from both converters. The optimum cesium temperatures at these conditions are 620 and 626°K. Figure 15 shows the cesium optimized envelopes of the two converters for several emitter temperatures. The agreement is within 20 mV throughout the range of operating conditions.

V. PERFORMANCE COMPARISON

In this section, thermionic performance of six preferred oriented tungsten emitters with several collector materials are compared. The performance data were obtained in the same type of variable spacing research converter, using the same processing, outgassing, cesiating, and temperature measurement techniques. The converters used the following pairs of electrodes:

Converter 47: Emitter: Duplex tungsten (20 mils of chloride tungsten on 150 mils of fluoride tungsten). Electro-polished and heat treated for 20 hours at 2300°K.
Bare work function: 4.98 eV.

Collector: Sublimed molybdenum ($\langle 110 \rangle$ preferred oriented) on bulk niobium.

Converter 46: Emitter: (same as 47).

Collector: Ground bulk niobium.

Converter 45: Emitter: Fluoride tungsten.
(Ref. 3)

Collector: Ground bulk niobium.

Converter 42: Emitter: Nominal $\langle 110 \rangle$ single crystal tungsten.
(Ref. 1)

Bare work function: 5.13 eV.

Converter 36: Emitter: Duplex tungsten. Bare work function:
(Ref. 4)

4.78 eV.

Collector: Ground bulk molybdenum.

Converter 32: Emitter: Same as 42 with the addition of oxygen.

Collector: Ground bulk molybdenum.

Figure 16 shows the performance comparison of these converters at the interelectrode spacing of 10 mils and the current density of 10 amps/cm^2 . Three groups of converters were observed. The lowest curve represents the performance of fluoride tungsten emitters (Reference 3). The middle group shows the performance of $\langle 110 \rangle$ tungsten emitters and represents the present state of the art. The top curve shows performance with oxygen additives and indicates what can be expected in the future.

Let us concentrate on the performance of the middle group of converters. The total difference in their performance is 0.1 volt. The emitter with the bare work function of 4.78 eV has the lowest performance; as the bare work function increases, the output power increases.

Although niobium and molybdenum collectors are used, the variations in converter performance can be explained solely by the variation in their emitter bare work functions. For example, there are two emitters with similar pole figures and bare work functions (4.98 eV) using niobium and $\langle 110 \rangle$ molybdenum collectors. There is, however, no difference in their performance.

Figures 17 and 18 show the power output comparison as a function of interelectrode spacing for emitter temperatures of 1800°K and 1900°K . The order of the curves has remained the same throughout the interelectrode spacing range. There is an additional data point (shown as the solid circle on this plot) from a fixed spacing converter⁶ with a different design. The converter was processed and outgassed in a manner similar to the variable spacing devices. Its emitter was chloride tungsten with a high $\langle 110 \rangle$ preferred orientation and a bare work function of

4.92 eV, and its power output is in close agreement with the WCl emitters having similar work functions.

An additional consistency can be observed in this group of converters. Table 1 shows the cesiated emission of the emitters for several emitter and cesium reservoir temperatures. The higher the bare work function, the higher the observed cesiated emission (and therefore the higher the power output). The qualitative correlation of bare work function and cesiated emission is observed with this group of $\langle 110 \rangle$ preferred oriented tungsten emitters and may not hold for other types of emitters. McCandless and Wilkins⁷ have shown that the bare work function correlation does not hold among the single crystal $\langle 110 \rangle$, $\langle 111 \rangle$ and $\langle 110 \rangle$ tungsten.

VI. EFFECT OF OFF-OPTIMUM COLLECTOR TEMPERATURE

For analysis of in-pile test data, it is often desirable to have data which show the effect of collector temperature on converter performance. Such data were obtained from the WCl-Mo* converter whose performance is in agreement with the WCl-Nb converters. Cesium families were obtained for the collector temperatures of 670, 770, 870 and 970°K at the emitter temperatures of 1600, 1700, 1800 and 1900°K and an inter-electrode spacing of 10 mils. A summary of the data is shown in Figures 19 to 21; the original data are shown in Appendix B. Generally, variations of 100°K around the optimum collector temperature do not reduce the output by more than 50 mV. Further deviations, however, result in a significant reduction in output.

ACKNOWLEDGEMENTS

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TABLE 1
COMPARISON OF CESIATED EMISSION AND BARE WORK FUNCTION

Converter	Bare Work Function eV	Short Circuit Current Density, amps/cm ²		
		T _E = 1600°K T _R = 551°K	T _E = 1800°K T _R = 564°K	T _E = 2000°K T _R = 591°K
⟨110⟩ W-Mo (42)	5.13	12.8	7.6	10.6
Cl W-Nb (46)	4.98	7.6	4.8	7.0
Cl W-Mo (36)	4.78	6.0	3.4	6.7

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Figure 1. Schematic Diagram of a Research Thermionic Converter.

Figure 2. Distribution of the $\langle 110 \rangle$ Axis in the Vapor-Deposited Emitters.

Figure 3. Typical Emitter Bare Work Function Data.

Figure 4. Variable Cesium Temperature Family at $T_e = 1600^\circ\text{K}$.

Figure 5. Variable Cesium Temperature Family at $T_E = 1700^\circ\text{K}$.

Figure 6. Variable Cesium Temperature Family at $T_e = 1800^\circ\text{K}$.

Figure 7. Variable Cesium Temperature Family at $T_e = 1900^\circ\text{K}$.

Figure 8. Variable Cesium Temperature Family at $T_e = 2000^\circ\text{K}$.

Figure 9. Cesium Optimized Envelopes for Several Interelectrode Spacings at $T_E = 1600^\circ\text{K}$.

Figure 10. Cesium Optimized Envelopes for Several Interelectrode Spacings at $T_E = 1700^\circ\text{K}$.

711-9

Figure 11. Cesium Optimized Envelopes for Several Interelectrode Spacings at $T_f = 1800^\circ\text{K}$.

711-10

Figure 12. Cesium Optimized Envelopes for Several Interelectrode Spacings at $T_E = 1900^\circ\text{K}$.

Figure 13. Cesium Optimized Envelopes for Several Interelectrode Spacings at $T_E = 2000^\circ\text{K}$.

Figure 14. Performance Comparison of the Original (left) and Rebuilt (right) Converter.

715-45

Figure 15. Comparison of Cesium Optimized Envelopes Before (solid curves) and After (dashed curves) Rebuilding the Converter.

Figure 16. Performance Comparison of Several Electrode Materials at an Interelectrode Spacing of 10 mils.

7010-16

Figure 17. Performance Comparison of Several Electrode Materials at an Emitter Temperature of 1800°K.

Figure 18. Performance Comparison of Several Electrode Materials at an Emitter Temperature of 1900°K.

715-49

Figure 19. Effect of Collector Temperature on Cesium Optimized Envelopes at $T_E = 1700^\circ\text{K}$.

Figure 20. Effect of Collector Temperature on Cesium Optimized Envelopes at $T_E = 1800^\circ\text{K}$.

715-47

Figure 21. Effect of Collector Temperature on Cesium Optimized Envelopes at $T_E = 1900^\circ\text{K}$.

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APPENDIX A

DETAILED PERFORMANCE DATA FOR
WCl-Nb CONVERTER

Figure A-1.

Figure A-2.

Figure A-3.

Figure A-4.

Figure A-5. Variable Cesium Temperature Family at $T_f = 1600^\circ\text{K}$.

Figure A-6.

Figure A-7.

Figure A-8.

Figure A-9.

Figure A-10.

Figure A-11.

Figure A-12.

711-3

Figure A-13. Variable Cesium Temperature Family at $T_E = 1700^\circ\text{K}$.

Figure A-14.

Figure A-15.

Figure A-16.

Figure A-17.

Figure A-18.

Figure A-19.

Figure A-20. Variable Cesium Temperature Family at $T_e = 1800^\circ\text{K}$.

Figure A-21.

Figure A-22.

Figure A-23.

Figure A-24.

Figure A-25.

Figure A-26.

Figure A-27. Variable Cesium Temperature Family at $T_e = 1900^\circ\text{K}$.

Figure A-28.

Figure A-29.

Figure A-30.

Figure A-31.

Figure A-32.

Figure A-33. Variable Cesium Temperature Family at $T_e = 2000^\circ\text{K}$.

Figure A-34.

APPENDIX B

EFFECT OF COLLECTOR TEMPERATURE
ON Cs FAMILIES

Figure B-1.

Figure B-2.

Figure B-3.

Figure B-4.

Figure B-5.

Figure B-6.

Figure B-7.

Figure B-8.

Figure B-9.

Figure B-10.

Figure B-11.

Figure B-12.