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COMPUTER ACQUIRED PERFORMANCE DATA FROM A CHEMICALLY VAPOR-DEPOSITED-RHENIUM, NIOBIUM PLANAR DIODE

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16. Abstract

Performance data from a chemically vapor-deposited-rhenium, niobium thermionic converter are presented. The planar converter has a guard-ringed collector and a nominal fixed spacing of 0.25 mm (10 mils). The data were obtained by using a computerized acquisition system and are available on request to one of the authors on microfiche as individual and composite parametric current, voltage curves. The parameters are the temperatures of the emitter T_E, collector T_C, and cesium reservoir T_R. The composite plots have constant T_E and varying T_C or T_R, or both. Current, voltage envelopes having constant T_E with and without fixed T_C appear in the present report. The diode was tested at increments between 1600 and 2000 K for the emitter Hohlraum, 800 to 1100 K for the collector, and 540 to 650 K for the reservoir. A total of 312 current, voltage curves were obtained in the present performance evaluation. Current, voltage envelopes from three rhenium emitter converters evaluated in the present program are also given. The data are compared at common emitter Hohlraum temperatures.

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COMPUTER ACQUIRED PERFORMANCE DATA FROM A CHEMICALLY VAPOR-DEPOSITED-RHENIUM, NIOBIUM PLANAR DIODE

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SUMMARY

A fixed-space planar diode with a guarded collector has been performance mapped in a multistation facility, which is connected to a centralized computer data acquisition system. The chemically vapor-deposited-rhenium emitter was separated from a niobium collector by 0.25 millimeter (10 mils). The use of the computer system allowed off-design as well as optimum conditions to be observed. Temperatures ranged from 1600 to 2000 K for the emitter Hohlraum (T_E), 800 to 1100 K for the collector (T_C), and 540 to 640 K for the cesium reservoir (T_R). The current, voltage envelopes with constant T_E and varying T_C and T_R and with constant T_E and T_C and varying T_R are presented.

Current, voltage envelopes from three rhenium emitter converters evaluated in the present program are also given. The data are compared at common emitter Hohlraum temperatures.

INTRODUCTION

More power at lower temperatures is the goal for nuclear thermionic diodes. Providing that improvement means intensive testing of the best existing emitters and collectors, promising new electrodes, and additives. To ensure success, performance mapping must cover off-design as well as optimum operating conditions. Part of this program is the evaluation of six planar diodes with guarded collectors of niobium or molybdenum spaced 0.25 millimeter from emitters of rhenium or tungsten (ref. 1). The results obtained for the electrode combination of a chemically vapor-deposited-rhenium emitter and a niobium collector are presented in this report. Similar results for emitters of physically vapor-deposited tungsten, chemically vapor-deposited tungsten, and

etched rhenium with niobium or molybdenum collectors are presented in references 2 to 6.

Performance data were recorded by using the computer system as described in reference 7. This data acquisition facility controls the application of a variable transistorized load and allows performance testing at off-design as well as optimum conditions.

Diagnostic ignition current data were also obtained to ascertain whether the chemically vapor-deposited-rhenium emitting layer was uniformly bonded to the face of the wrought-rhenium substrate. The procedure employed for these measurements as well as a discussion of the results is given in the appendix.

TEST FACILITY

Test Stations

The converters (fig. 1) were fabricated and then filled with cesium by the contractor.[1] They were mounted in vacuum test stations, six of which have a central instrumentation control panel. Each station has its own set of emitter (electron-bombardment), collector, and cesium-reservoir heat supplies. Thermal balance of the collector and reservoir is achieved through conduction to water lines.

Instrumentation

The current from the converter was measured by the voltage drop across either a 0.01- or a 0.1-ohm precision shunt. The emitter, collector potential difference was measured at the external shroud of the converter. No corrections were made for the voltage drop in the emitter support shroud since it is approximately 1.8 millivolts per ampere per square centimeter of electrode surface. The current density was determined for the 1.55-square-centimeter collector. The guard ring was connected to the circuit on the opposite side of the shunt from the collector.

The collector and cesium-reservoir temperatures were observed by using sheathed Chromel, Alumel thermocouples embedded in their respective converter structures. The thermocouples were continuous and were brought through the vacuum wall of the test station into a common ambient cold junction zone. The temperature of the ambient zone was sensed by a Chromel, Alumel thermocouple that was referenced electronically to 273 K. Two thermocouples were inserted at each location. The cesium-reservoir thermocouples were located in the copper block surrounding the copper tube containing

[1]Thermo Electron Engineering Corp., Waltham, Mass.

the cesium (fig. 1). The collector thermocouples were inserted to within 3.05 millimeters (125 mils) of the collector surface. The Chromel, Alumel standard calibration for all four thermocouples was verified by an in situ comparison against a Chromel, Alumel reference thermocouple.

The emitter temperature referred to in the present report was observed at the location of the Hohlraum in the wrought rhenium substrate of the emitter (see fig. 1) and is greater than the actual emitter surface temperature. Observations of this black-body cavity (length-diameter ratio of 5) were made through a window in the test station with an automatic disappearing-filament optical pyrometer. The optical path and pyrometer were calibrated against a National Bureau of Standards (NBS) tungsten strip lamp. The maximum uncertainty associated with the observed temperature is approximately ±10 K.

The temperature of the active face of the chemically vapor-deposited rhenium was difficult to estimate because of the possibility of a poor bond between the deposit layer and the substrate (ref. 8). Structurally similar samples have yielded temperature differences ranging from 15 to 20 K for good bonds to almost 120 K for poor bonds (ref. 8). Rather than introducing uncertain emitter temperature gradient corrections during the actual data gathering phase, performance data were obtained at selected Hohlraum temperatures. Electron cooling effects on the surface temperature are negligible during the data observation period since the time interval over which the load is applied is very short and the converter is held at a low-current, retarded-voltage condition between tests (ref. 7).

TEST PROCEDURE

The computer-controlled data acquisition system is programmed to trigger the variable load at up to six different emitter temperatures during a given test interval, which is usually approximately 20 seconds. (The program was developed by E. J. Manista and C. T. Kadow of the Lewis Research Center.) This is accomplished by sensing the emitter temperature and, upon its reaching a predetermined value, initiating a load variation. The actual temperature levels at which the system is triggered are introduced into a program by the operator as independent input data. The data recording program, synchronized with the variable load, samples the J, V (current density, voltage) characteristic of the converter at 90 points during the load application of approximately 10-millisecond duration. Sample and hold amplifiers coordinate in time the collector current and the collector, emitter potential difference.

The converter was mapped by fixing the temperatures of the cesium reservoir and the collector and heating the emitter to the predetermined levels. Two emitter temperature ramps were used to obtain data at 50 K increments between 1600 and 2000 K. The collector temperature was then changed, and the preceding procedure was repeated.

Observations were made at 100 K collector increments between 800 and 1100 K and at 950 K for the 2000-to-1800-K emitter ramp. For the 1600-to-1750-K emitter ramp, data were obtained at 800, 900, and 1000 K for the collector. For the higher emitter ramp the cesium reservoir was run at 560, 580, 590, 600, 610, 620, 630, and 640 K, and for the lower emitter ramp the cesium reservoir was run at 540, 550, 560, 580, 590, and 600 K. At least one pulse of the variable transistorized load was made at each one of the reservoir-, collector-, and emitter-temperature combinations. All temperatures were recorded at the end of each J, V sweep. Between sweeps these analog temperatures were converted by the computer to their values in kelvin and then printed out for use by the operator in setting conditions.

PERFORMANCE OF THE CHEMICALLY VAPOR-DEPOSITED RHENIUM, NIOBIUM CONVERTER

Since the local computer can store and recall only a limited number of successive sweeps, the data are transmitted to the Lewis Central Computing Center for storage on magnetic tape and for some engineering calculations. The data are sorted into groups of common emitter temperatures and are displayed in order of ascending T_E on microfilm output. Both J, V and P, V (power-density, voltage) curves are displayed, with the J and P scales being determined by the maximum of each sweep. Two additional sorts are done by the central computer: the data are grouped by common emitter and collector temperatures and by common emitter and reservoir temperatures. The computer plots all sorted J, V data on parametric composites and displays them on the microfilm output. These have scales of -0.5 to 2 volts and 0 to 30 amperes per square centimeter.

Table I lists the temperature conditions at which current, voltage data were obtained. The envelopes with varying T_C and T_R for emitter Hohlraum temperatures of 1600, 1700, 1800, 1900, and 2000 K are presented in figure 2. These envelopes represent the optimum performance of the converter at the fixed gap condition of 0.25 millimeter (10 mils). Current, voltage points along an envelope belong to varying temperatures of the collector and cesium reservoir.

The performance envelopes as a function of T_C are given in figure 3 for these same emitter Hohlraum temperatures. Inspection of these data reveals that operation of the collector at temperatures of 1000 K or greater results in a loss of output voltage for current densities of 9 amperes per square centimeter or lower. Moreover, the performance of the diode for current densities below 12 amperes per square centimeter is sensitive to variations in the collector temperature.

In all, 312 individual J, V plots were generated in developing these envelopes. These and the J, V composites are available on microfiche upon request to one of the authors.

PERFORMANCE COMPARISON OF RHENIUM EMITTER CONVERTERS

Three planar converters with rhenium emitters have been extensively performance-mapped during the current program. As a summary, figure 4 presents constant emitter Hohlraum temperature envelopes at 1700, 1800, 1900, and 2000 K for these converters. The data for the etched-rhenium, molybdenum converter is that of reference 6. The data for the etched-rhenium, niobium converter is that of references 4 and 10. On the basis of maximum output electrode power, the etched-rhenium, niobium diode is clearly superior.

Inherent in the preceding comparison are the assumptions that the interelectrode spacings of the three converters corresponds to the nominal design value of 0.25 millimeter (10 mils) and that the emitter surface temperatures are represented by emitter Hohlraum temperatures. In the case of the etched-rhenium, niobium converter, the assumption of a 0.25-millimeter (10-mil) spacing may not be valid. Since interelectrode spacing cannot be directly measured, a diagnostic technique, based on the ignition-current, spacing correlation established by the work reported in reference 9 was applied to the etched-rhenium, niobium data files of references 4 and 10. (A discussion of this technique appears in the appendix of this report.) The magnitudes of the ignition-current-densities found in the etched-rhenium, niobium converter ranged from 1.4 amperes per square centimeter at an emitter temperature of 1700 K to nearly 3 amperes per square centimeter at an 1850 K emitter temperature. Ignition current densities of these levels imply an interelectrode spacing of about 0.12 millimeter (5 mils). The same diagnostic technique was applied to the two other rhenium emitter converters. In both cases reduced levels of ignition current density were found, and the interelectrode spacings implied were consistent with the nominal design value of 0.25 millimeter (10 mils).

CONCLUDING REMARKS

Performance envelopes of the thermionic output from a chemically vapor-deposited-rhenium, niobium planar converter are given in this report. The data are referenced to the measured emitter Hohlraum temperature since the ignition-current diagnostic procedure was not capable, in this case, of defining a suitable emitter temperature correction.

Comparisons of the thermionic performance, at constant emitter Hohlraum temperatures, are also given for the present converter; an etched-rhenium, niobium converter; and an etched-rhenium, molybdenum converter. The superior performance of the etched-rhenium, niobium converter can be partly attributed to the interelectrode spacing

effect. Ignition-current diagnostics support the existance of a 0.12-millimeter (5-mil) gap in this converter; whereas, the gap in the other two converters is closer to 0.25 millimeter (10 mils).

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 27, 1973,
503-25.

APPENDIX - DIAGNOSTIC TEST RESULTS

Envelope Verification

During data accumulation an anomalous ignited-mode structure was sometimes observed in the J,V characteristic. Qualitatively, the current to the collector increased more rapidly during the anomaly than an extrapolation from a normal ignited-mode characteristic would indicate. The region of the characteristic affected occurred near zero output voltage. The effect was dependent upon the cesium pressure in the gap and also on the length of time that the converter was held at high cesium pressures. Figure 5 presents data obtained from a test designed to investigate whether this anomalous structure significantly influenced the performance envelope. The data shown as a solid line in figure 5 were obtained on an increasing cesium-reservoir temperature ramp after the converter had been held overnight at a low cesium pressure (350 K) and with the emitter at 1800 K. Each cesium pressure was established and held at the desired value for at least 5 minutes before obtaining a J,V curve. Upon reaching the nominal 640 K reservoir level, the converter was held for about 2 hours at this cesium pressure with the emitter at 1800 K. The data obtained during the descending cesium pressure ramp are shown as the dashed lines in figure 5. Although individual current, voltage curves show considerable nonreproducibility, the performance envelopes generated in the ascending and descending cesium pressure ramps are indiscernible.

Current, voltage characteristics having properties similar to those just described have been observed before (ref. 10). In the tests of reference 10, the increased ignited mode current was forced by externally shorting the guard-ring current-carrying lead to the emitter, thus self-biasing the guard-ring electrode negatively. The collector potential could then become more positive than the guard-ring potential during the voltage sweep used to obtain the current, voltage characteristic. When this positive collector, guard-ring potential imbalance occurred, an increased current flow to the collector electrode was always observed. Thus the anomalous ignited mode structure, which was sometimes observed during the performance mapping of this converter, may very well have been caused by an intermittent, internal shorting of the guard-ring electrode to the emitter support structure of the device.

Ignition Current-Density Correlation

As mentioned earlier, the actual emitter surface temperatures for these performance data are not precisely known because of the suspected poor bonding of the deposited rhenium layer on the wrought rhenium substrate. Since the thermal impedance of the bond interface is unknown, estimates of emitter temperature gradients were obtained by using the ignition-current-density, emitter-temperature, cesium-reservoir-temperature,

electrode-spacing correlation suggested in reference 9. This correlation provides a basis for a semiquantitative assessment of both spacing and emitter surface temperature from observations of the ignition current density as a function of cesium-reservoir temperature. It is recognized that this correlation is dependent upon converter configuration; but fortunately, the converter geometry employed in reference 9 is identical to the fixed space planar converter evaluated in this report. As shown experimentally in reference 9, the ignition current density is a sensitive function of interelectrode spacing, a 0.05-millimeter (2-mil) error at a spacing of 0.25 millimeter (10 mils) can result in an error of 50 K in emitter temperature.

Ignition current data were obtained with the Hohlraum at 1700, 1750, 1800, 1850, and 1900 K and with the cesium reservoir at 575, 600, and 625 K. The standard test circuit was used with manual triggering of the electronic load. A calibrated oscilloscope monitored the voltage drop produced across the collector current shunt. Each of the test conditions was repeated randomly at least three times to ensure a reproducible measurement of the ignition current density.

Table II is a summary of the results. The first three columns tabulate observed values of ignition current as a function of Hohlraum temperature and cesium-reservoir temperature. The next three columns give the emitter surface temperature for spacings of 0.20 millimeter (8 mils), 0.25 millimeter (10 mils), and 0.30 millimeter (12 mils) that correspond to the values of ignition current and cesium-reservoir temperature. These values of emitter temperature were taken from figures 10a, b, and c of reference 9. The general trend is that the smaller the spacing, the larger is the implied temperature drop between the Hohlraum and the emitter surface.

The data are consistent with gaps from 0.20 to 0.30 millimeter and imply that a considerable temperature correction is required. However, adopting this approach leads to a serious inconsistency when the performance envelopes of the chemically vapor-deposited rhenium, niobium diode are compared to those of the etched-rhenium, niobium diode. The performance of the chemically vapor-deposited-rhenium, niobium diode at a spacing of 0.25 millimeter is superior to that of the etched-rhenium, niobium diode at a spacing of 0.12 millimeter. And this conclusion is difficult to accept.

A possible explanation for the lack of quantitative agreement may reside in the assumption of a reasonably uniform temperature distribution across the emitting surface of the chemically vapor-deposited rhenium. The sensitivity of the ignition-current correlation to a perturbation of this type has yet to be defined. Attempts to apply the planar correlation to cylindrical converters, which possess large axial temperature gradients, have also been unsuccessful.

Thus, the question of whether a poor bond exists between the chemically vapor-deposited-rhenium layer and the substrate remains unanswered.

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TABLE I. - TEMPERATURE RANGES OF DATA INCLUDED IN PERFORMANCE MAP

Emitter Hohlraum temperature, T_E, K	Collector temperature, T_C, K	Cesium-reservoir temperature, T_R, K	Number of current, voltage curves
1600	794 to 992	539 to 601	18
1650	797 to 993	540 to 601	18
1700	801 to 1000	540 to 601	18
1750	804 to 1002	540 to 602	18
1800	794 to 898	559 to 640	16
1800	895 to 1095	560 to 643	24
1850	798 to 902	558 to 640	16
1850	901 to 1099	561 to 643	24
1900	799 to 906	558 to 640	16
1900	903 to 1102	560 to 644	24
1950	800 to 903	558 to 639	16
1950	905 to 1104	560 to 643	24
2000	801 to 908	557 to 640	16
2000	906 to 1104	560 to 642	24

TABLE II. - IGNITION CURRENT CORRELATION

Cesium-reservoir temperature, T_R, K	Emitter Hohlraum temperature, T_E, K	Ignition current density, J, A/cm^2	Emitter surface temperature, $T_E(T_R, J, d)$, K, at interelectrode spacing of -		
			0.20 mm (8 mils)	0.25 mm (10 mils)	0.30 mm (12 mils)
575	1700	0.28	1622	1633	1637
600	1700	.20	1617	1624	1630
625	1700	.15	1615	1622	1630
575	1750	.43	1650	1665	1673
600	1750	.33	1643	1660	1667
625	1750	.24	1635	1650	1660
575	1800	.60	1680	1703	1713
600	1800	.47	1670	1695	1708
625	1800	.36	1660	1685	1698
575	1800	.60	1680	1703	1713
600	1800	.46	1668	1692	1704
625	1800	.35	1660	1683	1695
575	1850	.77	1710	1740	1755
600	1850	.60	1696	1730	1743
625	1850	.46	1685	1715	1732
575	1900	.94	1740	1780	1795
600	1900	.77	1732	1775	1792
625	1900	.62	1722	1768	1787

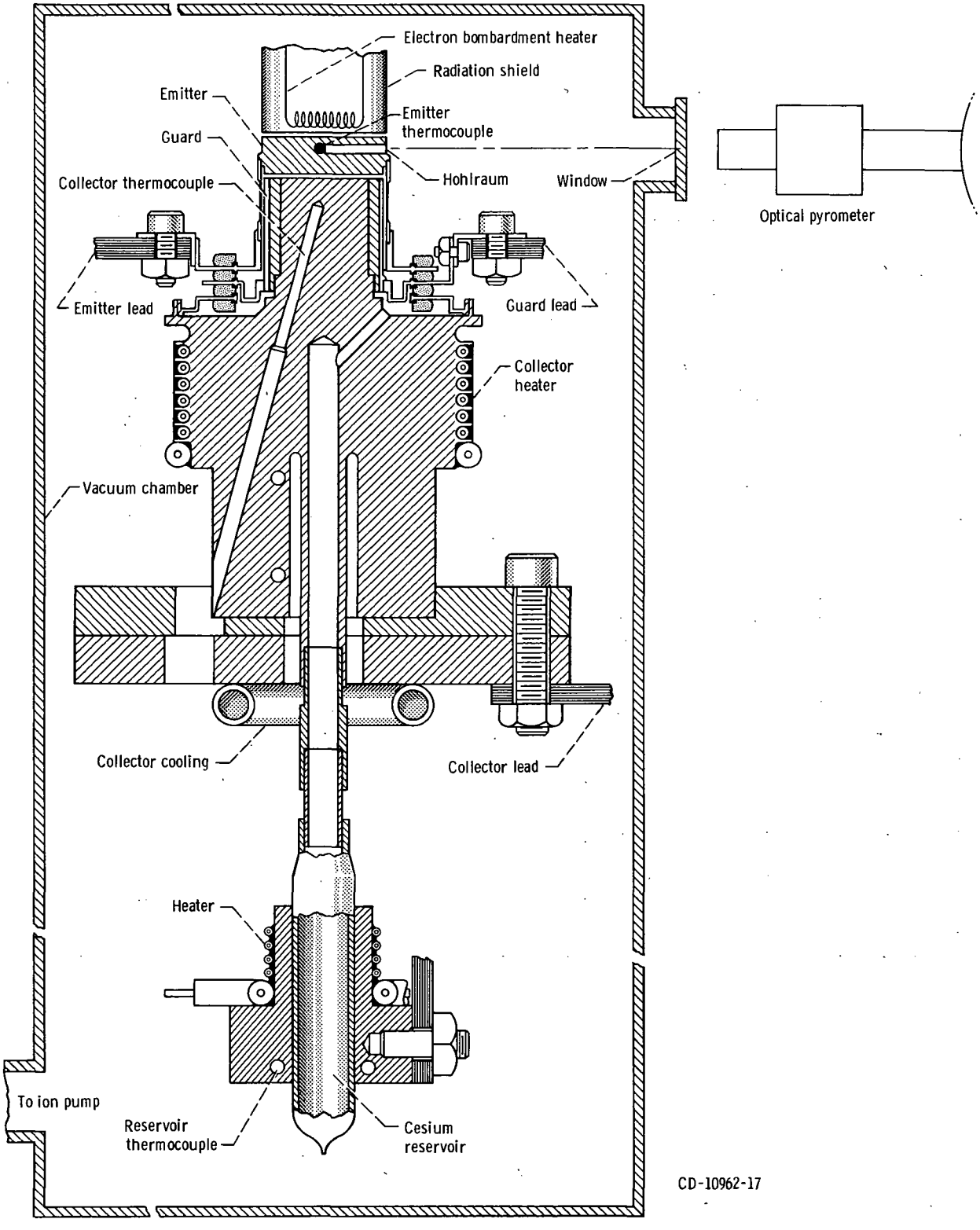


Figure 1. - Converter configuration.

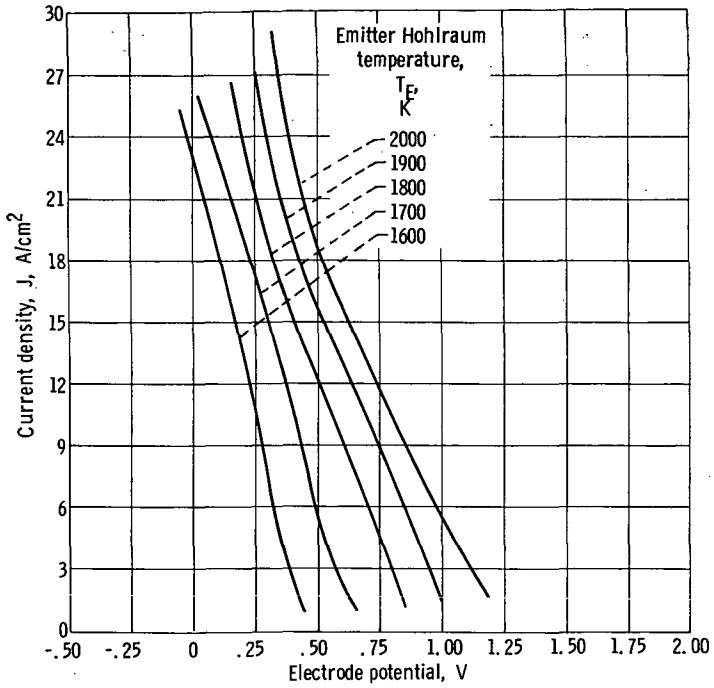
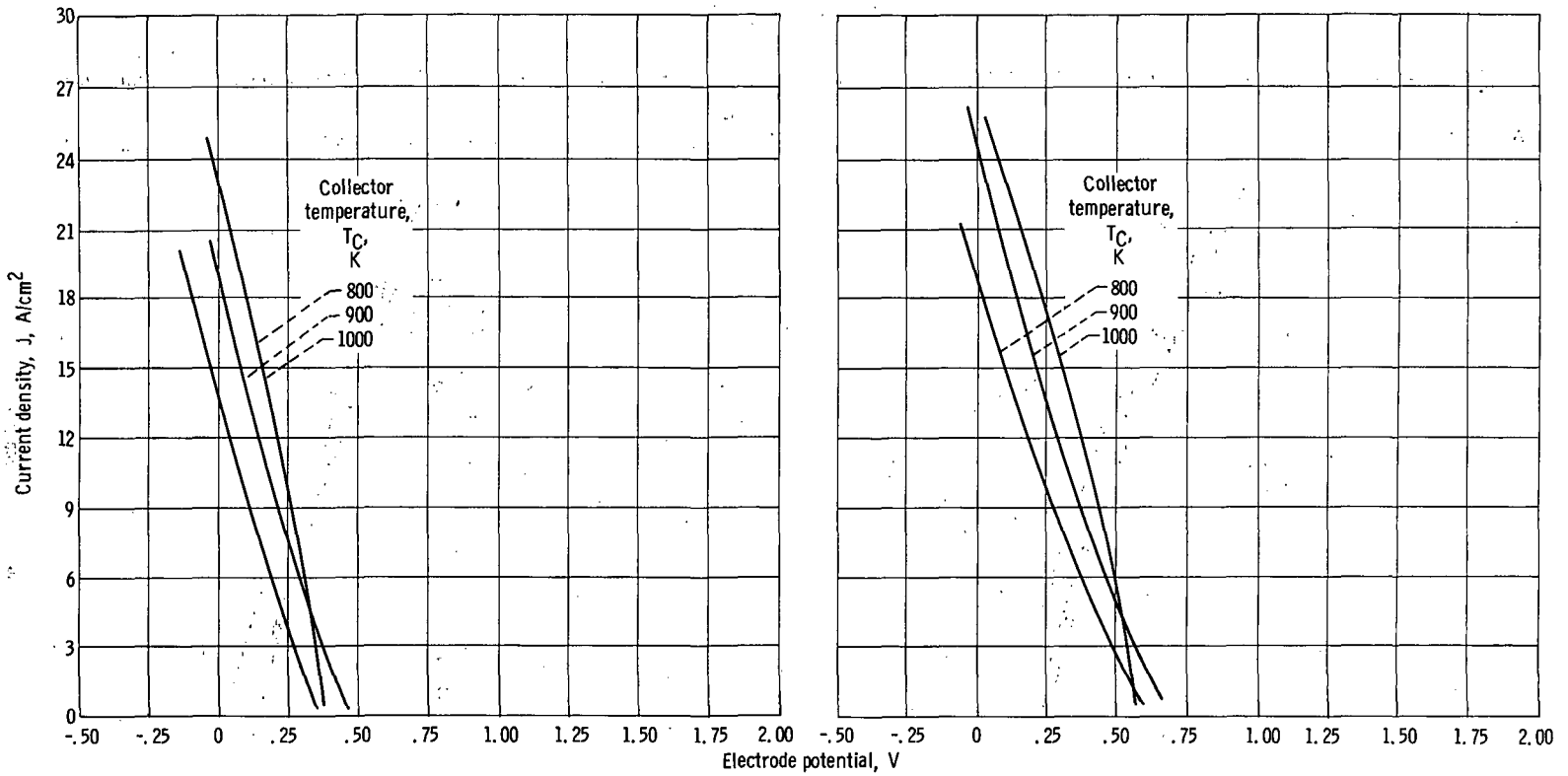


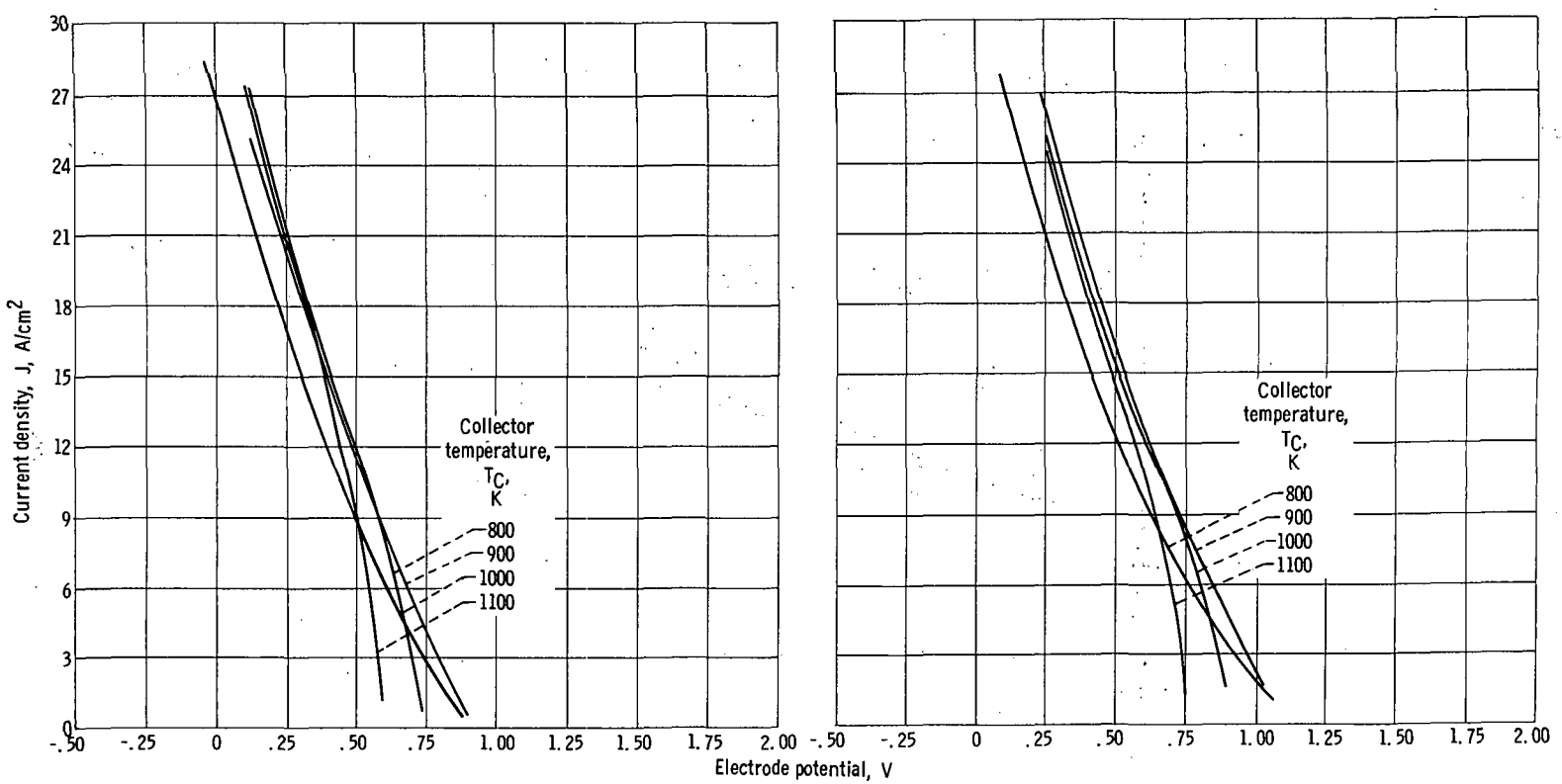
Figure 2. - Envelopes for chemically vapor-deposited-rhenium, niobium planar converter at various emitter Hohlraum temperatures.



(a) Emitter Hohlraum temperature, 1600 K; cesium-reservoir temperature range, 539 to 601 K.

(b) Emitter Hohlraum temperature, 1700 K; cesium-reservoir temperature range, 540 to 601 K.

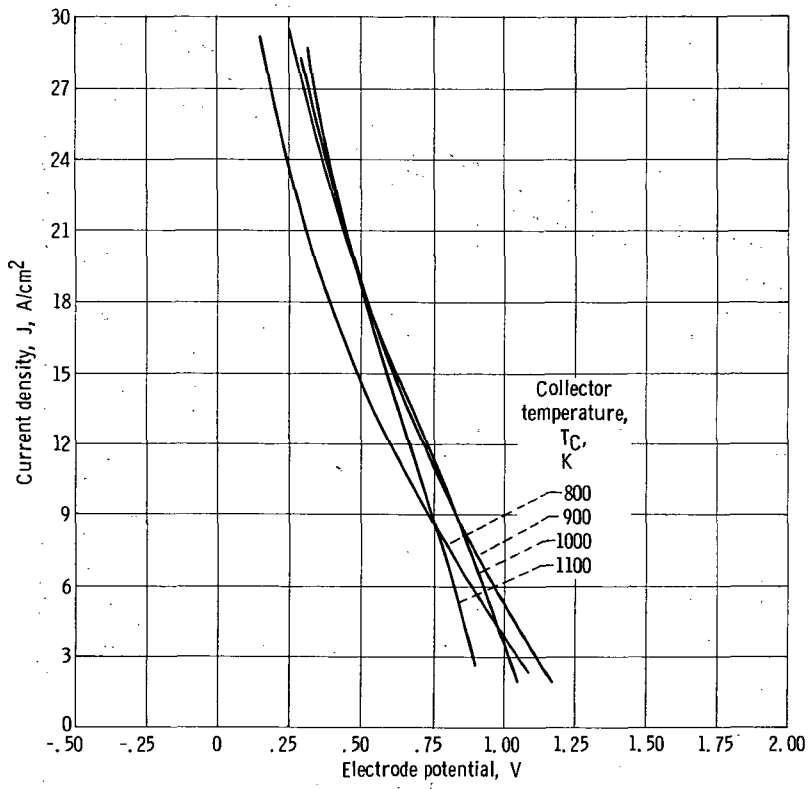
Figure 3. - Envelopes for chemically vapor-deposited-rhenium, niobium planar converter at various collector temperatures.



(c) Emitter Hohlraum temperature, 1800 K; cesium-reservoir temperature range, 559 to 643 K.

(d) Emitter Hohlraum temperature, 1900 K; cesium-reservoir temperature range, 558 to 644 K.

Figure 3. - Continued.



(e) Emitter Hohlraum temperature, 2000 K; cesium-reservoir temperature range, 557 to 642 K.

Figure 3. - Concluded.

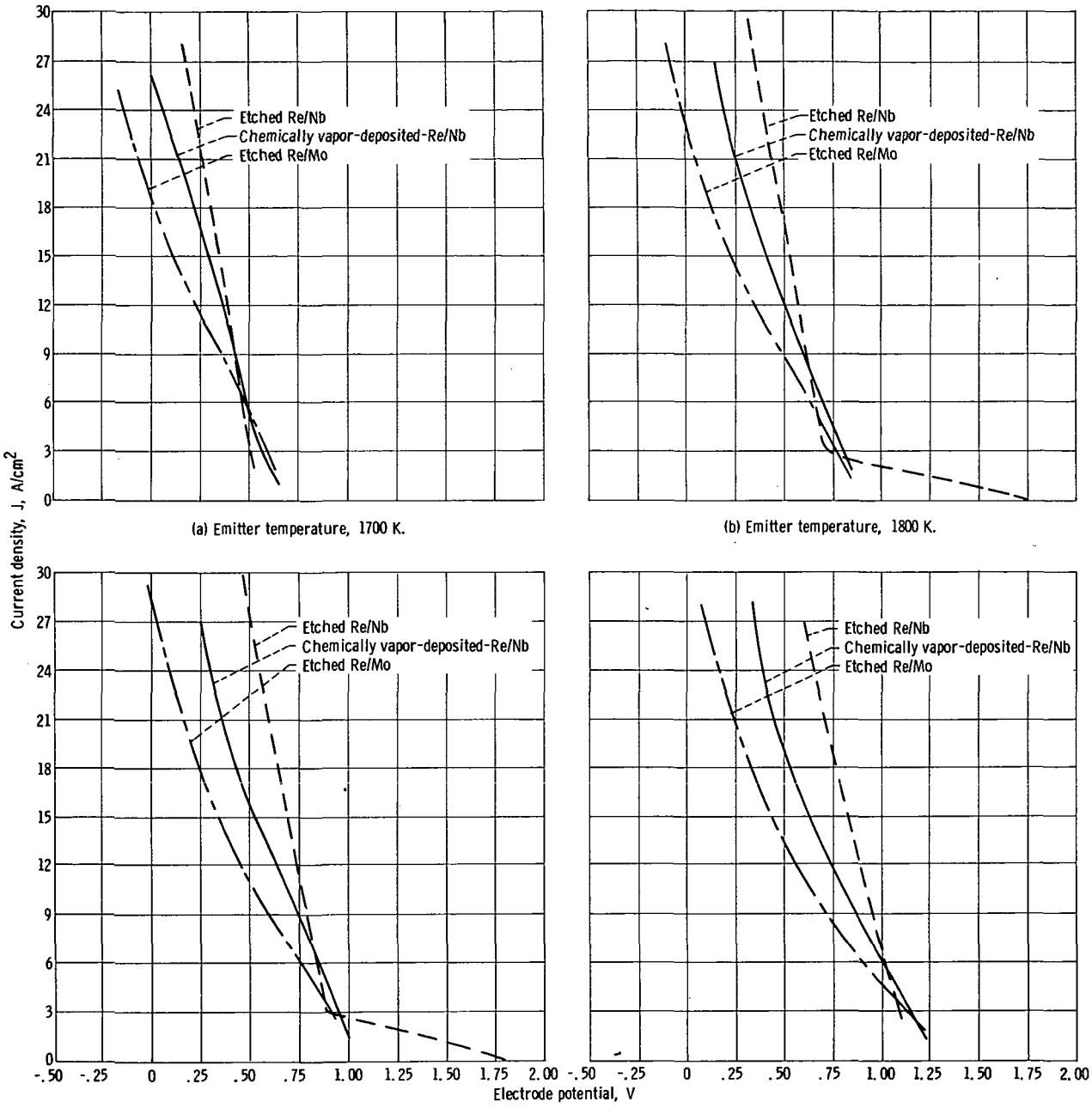


Figure 4. - Comparison of constant emitter temperature envelopes from various rhenium emitter planar diodes.

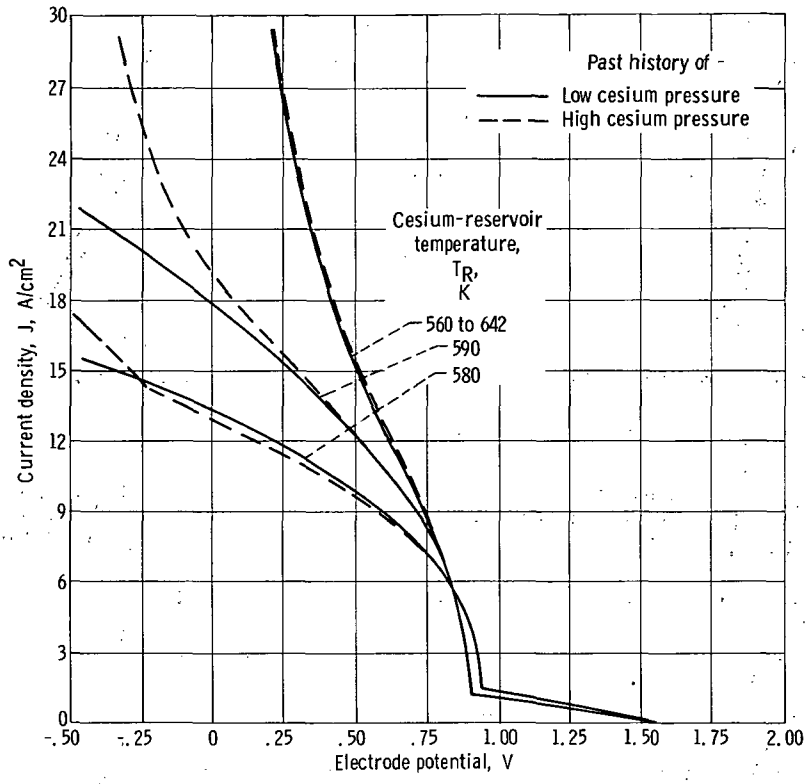


Figure 5. Envelopes showing effects of cesium pressure history on converter performance. Emitter Hohlraum temperature, 1900 K; collector temperature, 950 K.

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