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Summary

Performance of multistage depressed collectors (MDC's) using novel textured carbon on copper substrate electrode surfaces was evaluated in conjunction with medium-power traveling wave tubes (TWT's). MDC and TWT overall efficiencies for these novel electrodes were measured and compared with those obtained with the same TWT and a copper electrode MDC of identical design. Long-term stability of the carbon-coated copper electrode surfaces was investigated by periodic evaluation of TWT-MDC performance over an extended period of continuous wave (CW) operation. Application of textured carbon coating on copper MDC electrode surfaces produced a 13-percent improvement in both MDC and TWT overall efficiencies for the TWT-MDC tested. During 1600 hr of CW operation with a medium power TWT, no significant changes in MDC performance were observed. This indicated good stability of the textured carbon electrode surfaces. This stability was confirmed by scanning electron microscope examinations of the electrode surfaces before assembly of the MDC and after completion of the test program.

Introduction

A novel technique for depositing textured carbon surfaces on copper substrates is described in reference 1. The resulting textured carbon on copper surface has been shown experimentally to have secondary electron emission characteristics that are sharply lower than those of untreated copper. This technique, when applied to the machined copper electrodes commonly being used in multistage depressed collectors (MDC's), can lead to substantial improvements in MDC and traveling-wave-tube (TWT) efficiencies because of the attendant reduction of secondary electron emission losses in the MDC (ref. 2).

An experimental program involving two representative MDC's and TWT's was conducted to quantify the efficiency improvements possible and to evaluate the long-term stability of textured carbon surfaces under the intense electron bombardment encountered in small MDC's operated in conjunction with medium-power TWT's. This paper presents the results of the following tests:

(1) A study of TWT and MDC performance (under pulsed operating conditions) to compare carbon-coated copper MDC electrodes with untreated copper MDC electrodes
(2) A 600-hr test (under pulsed conditions) to determine the short-term stability (tens to hundreds of hours) of carbon-coated copper electrode surfaces under various electron bombardment intensities
(3) A 1600-hr (CW) extended test to determine long-term stability of the electrode surfaces

The TWT and MDC performance of textured carbon-coated copper electrodes was compared to that of untreated copper electrodes by using them sequentially in the same TWT with geometrically identical MDC's. Evaluation of the stability of the textured carbon surface was based on (1) periodic measurements of the MDC performance over the test duration and (2) scanning electron microscope examinations of selected areas of the MDC electrodes before assembly of the MDC's and following completion of the test program. Different TWT-MDC combinations were used for the pulsed and continuous wave (CW) tests.

Symbols

f	operating frequency, GHz
I_B	intercepted-beam current, A
I_{en}	current to collector electrode n, A
I_G	total body current, including backstreaming from collector, A
I_0	beam current, A
I_s	backstreaming current to the TWT body, A
P_{body}	body power, sum of RF-circuit losses and intercepted-beam power in forward direction, W
P_{col}	collector power, $V_0I_0 - P_{RF} - P_{body}$, W
P_{in}	RF input power
P_{rec}	recovered power, $\sum_{n=1}^{4} (\lvert V_0\rvert - V_{en})I_{en}$, W
P_{RF}	total radiofrequency (RF) output power, W
V_{en}	voltage on collector electrode n with respect to cathode, V
V_0	cathode potential with respect to ground, V
η_{col}	collector efficiency, P_{rec}/P_{col}, percent
η_c	TWT circuit efficiency, $P_{RF}/(P_{RF}$ + circuit losses), percent

η_e TWT electronic efficiency, η_{RF}/η_c

η_{ov} TWT overall efficiency, P_{RF}/(net dc input power), percent

η_{RF} RF efficiency of TWT, P_{RF}/V_0I_0, percent

Deposition of Textured Carbon on Copper

The method of sputter-applying a thin layer of highly textured carbon on copper substrates was developed at the NASA Lewis Research Center (ref. 1). Briefly, this method consists of depositing carbon from high-purity targets onto copper substrates in a low-pressure triode sputtering facility using specially determined geometric arrangements, operating parameters, and sputtering periods. The resulting surface is characterized by a dense random array of microscopic carbon peaks, or spires, which project perpendicularly from the local copper surface with average heights and spacings of approximately 10 and 4 μm, respectively. The morphology of the textured surface, shown in figure 1, is quite similar to those of the ion-textured graphites reported in references 3 and 4.

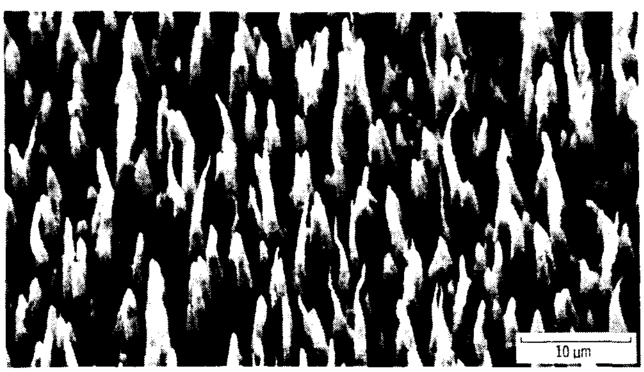


Figure 1.—Scanning electron microscope photomicrograph of fully developed textured carbon surface on copper substrate. Angle with surface, 30°.

TWT and MDC Characteristics

The pulsed tests were performed with a Varian Model 6336 A1 TWT, the characteristics of which are shown in table I. For convenience, this TWT is referred to as VA 101 throughout this report. The geometry and characteristics of its MDC, designated as MDC 1, are shown in figure 2 and table II, respectively. The number of collector stages is defined as the number of distinct voltages (other than ground) needed to operate the MDC. MDC 1, which does not use a separate electrode at ground potential, was operated in both three- and four-stage configurations. In the three-stage configuration, electrodes 1 and 2 were operated at the same voltage.

The CW test was performed with a Teledyne MEC Model MTZ-7000 TWT, designated as T MEC 103 in this report. The characteristics of this TWT are shown in table I. The

TABLE I.—GENERAL TWT CHARACTERISTICS

TWT characteristics	Pulsed tests using Varian 6336 A1	CW test using Teledyne MEC MTZ-7000
Serial number	101 R1	103
Designation	VA 101	T MEC 103
Frequency, GHz	2.5 to 5.5	4.8 to [a]9.6
Cathode voltage, kV	−6.2	−9.9
Cathode current, A	0.60	0.40
Perveance, $A/V^{3/2}$	1.23×10^{-6}	0.4×10^{-6}
TWT electronic efficiency, η_e, percent	26 (max)	16 (max)
Focusing	[b]PPM	[b]PPM
Duty cycle, percent	[c]25	100

[a]Limited to 6.4 GHz during the CW extended test.
[b]Periodic permanent magnet.
[c]Nominally CW, limited to 25 percent during these tests.

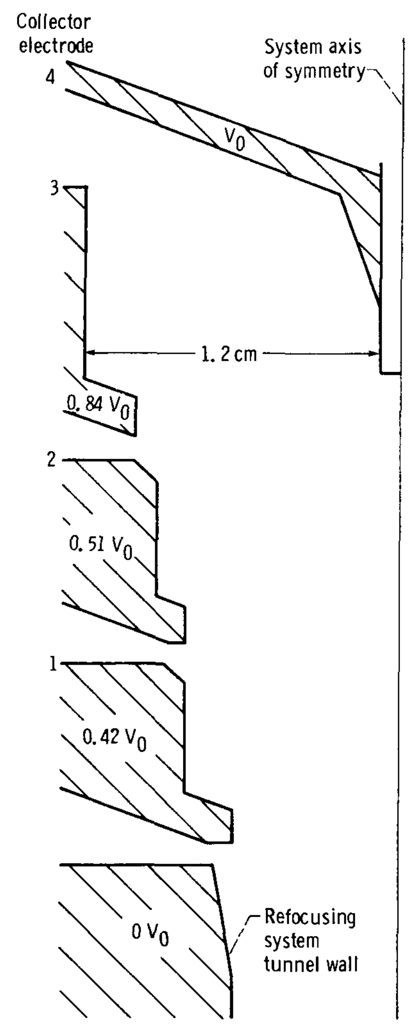


Figure 2.—Active electrode geometry and typical applied potentials for MDC 1.

TABLE II.—GENERAL MDC CHARACTERISTICS

MDC designation	MDC 1	MDC 3
Applicable TWT	VA 101	T MEC 103
Number of stages	4 or 3	4
Active inner diameter, cm	2.4	2.4
Active height, cm	3.2	3.8
Geometry	See figure 2	See figure 3
Typical MDC efficiency	Medium	High

geometry and characteristics of its MDC, designated as MDC 3, are shown in figure 3 and table II, respectively.

These TWT and MDC designations follow those established in reference 5, where these same TWT's and MDC designs (as well as others) were used in a study involving secondary electron emission losses in MDC's. Flow diagrams illustrating the distributions of power and electron current are shown in figure 4 for the TWT-refocuser-MDC system.

Both MDC's used the type of demountable mechanical design described in reference 6. MDC 1, which was operated only under pulsed conditions, was radiation cooled for

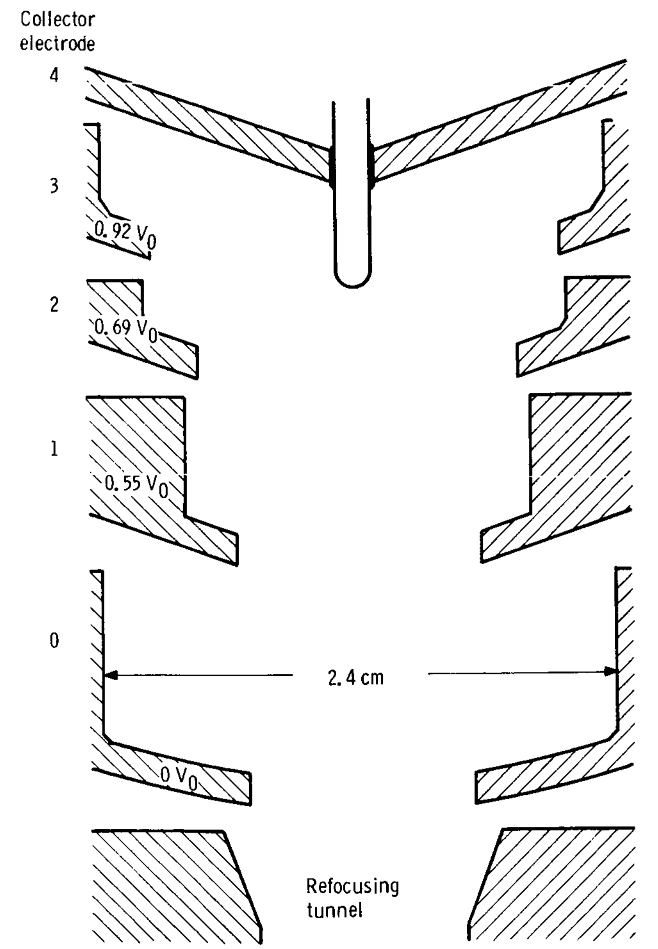
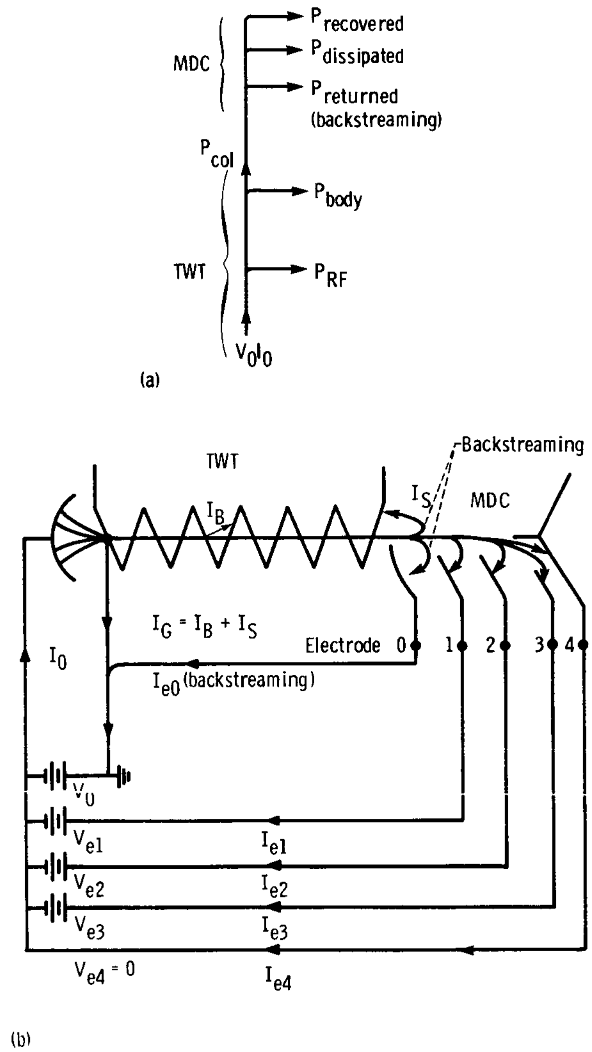


Figure 3.—Active electrode geometry and typical applied potentials for MDC 3.



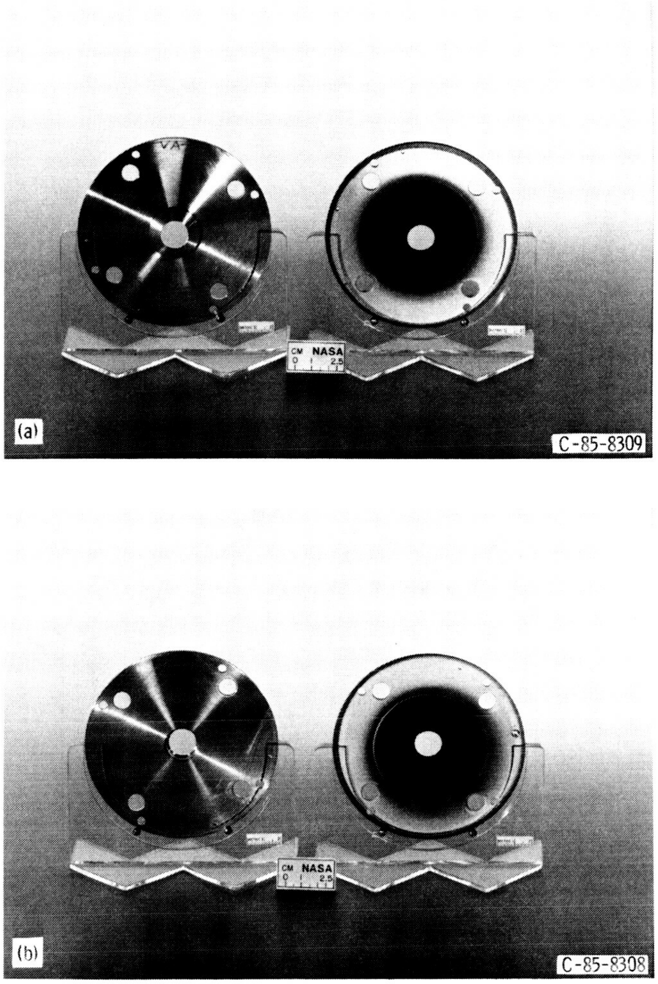
(a) Power flow.
(b) Electron flow.

Figure 4.—Flow diagrams for TWT with four-stage depressed collector.

convenience. Each electrode of MDC 3, which was operated CW, was water cooled. The total thermal power dissipated in MDC 3 was measured.

The photographs in figure 5 contrast the appearance of untreated copper electrodes with dimensionally identical textured-carbon-coated copper electrodes for the MDC 1 radiation-cooled configuration. Note that the textured carbon coating was applied to a larger area than that enclosed by the approximately 1-in. active electrode diameter. While it is difficult to discern from the photographs because of the low light reflectance of the coating, the electrodes in figure 5 have the same central geometry as electrode 2 in figure 2.

Figure 6 shows the trajectories of typical charges in the collectors of the TWT operating at saturation. These can be used to determine regions of high-intensity electron bombardment.



(a) Convex sides of untreated and textured-carbon-coated electrodes (left and right side, respectively).
(b) Concave sides of untreated and textured-carbon-coated electrodes (left and right side, respectively).

Figure 5.—Untreated and textured-carbon-coated radiation-cooled demountable MDC 1 electrodes.

Before the collectors were assembled, selected areas of the textured-carbon-coated electrode surfaces were examined with a scanning electron microscope so that the surface characteristics could be compared with those present after completion of the test program with the TWT's.

Experimental Program

After the textured-carbon-coated copper electrodes were tested and their performance was compared to that of untreated copper electrodes, they were subsequently used for the short-term surface durability test. The performance of these textured-carbon-coated copper electrodes can also be compared to that of electrodes coated with the other forms of carbon described in reference 5 because tests of these electrodes were also performed with VA 101 and MDC 1 under identical operating conditions.

T MEC 103 and MDC 3 were used for the extended CW test to determine the long-term durability of the carbon-coated copper electrode surfaces. Although T MEC 103 was previously operated with carbon black and pyrolytic graphite versions of MDC 3 (ref. 5), the TWT had subsequently undergone significant performance changes (discussed later). Consequently, this test produced no comparisons of TWT-MDC performance for carbon-coated copper surfaces with that of other electrode surfaces.

Experimental Arrangement and Procedure

The TWT and demountable MDC measuring system described in reference 6 was used to optimize and measure the TWT and MDC efficiencies. Because VA 101 had an ultra-high vacuum (UHV) valve at the end of the refocusing section (e.g., figs. 4 and 6 of ref. 6), this same TWT could be operated with a series of collectors without losing vacuum (ref. 7). Test-to-test TWT performance changes were minimized because no high-temperature TWT bakeout (nor removal of magnets from the PPM stack) was required. The TWT RF output power and total body losses were measured previously with an undepressed collector (ref. 8). Consequently, the MDC and TWT overall efficiencies could be computed from measured quantities on subsequent MDC tests as long as the RF performance of the TWT stayed relatively constant.

T MEC 103, which also had a UHV valve, was tested earlier with carbon black and pyrolytic graphite versions of MDC 3. However, subsequent to these tests the TWT RF performance (P_{RF} and P_{body} as functions of operating frequency) was found to be substantially altered. Consequently, a meaningful comparison of the performance of the textured-carbon-coated copper version of MDC 3 to those versions tested previously was not possible, and the extended CW test was limited to evaluating changes in MDC performance with time (long-term electrode surface stability).

The TWT's had a variable refocusing system consisting of two coils. The TWT and MDC performance was optimized by varying the coil locations and currents, as well as the collector electrode voltages and the length of the spike, as described in reference 6.

Filtered input drive at the fundamental frequency was used throughout these tests. Saturation was set using an uncalibrated power meter which (by means of a low-pass filter) measured RF output power only at the fundamental frequency. However, only the total RF power that was dissipated in the water-cooled matched load was measured, and all TWT overall and electronic efficiencies reported here are based on this P_{RF}.

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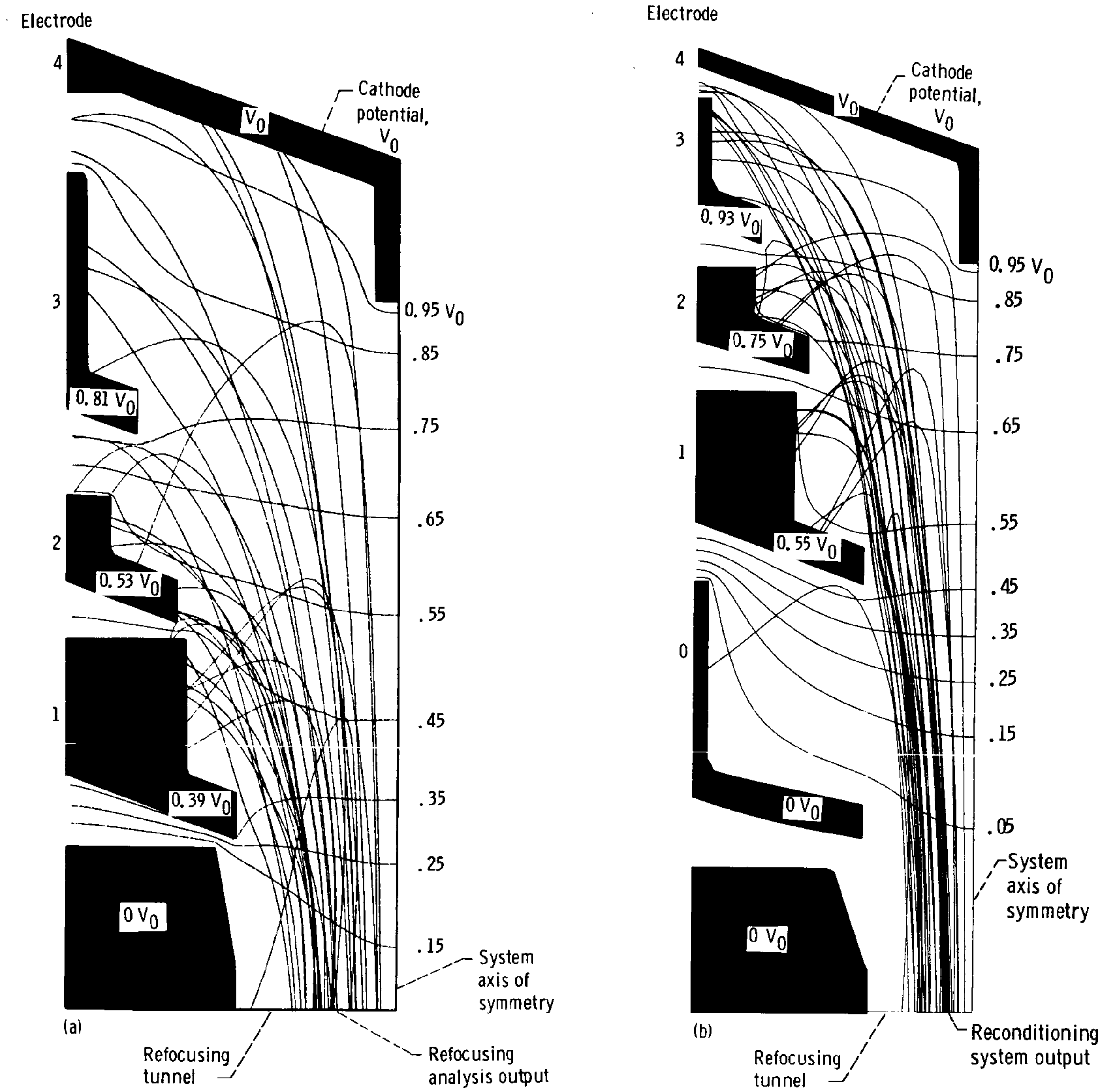


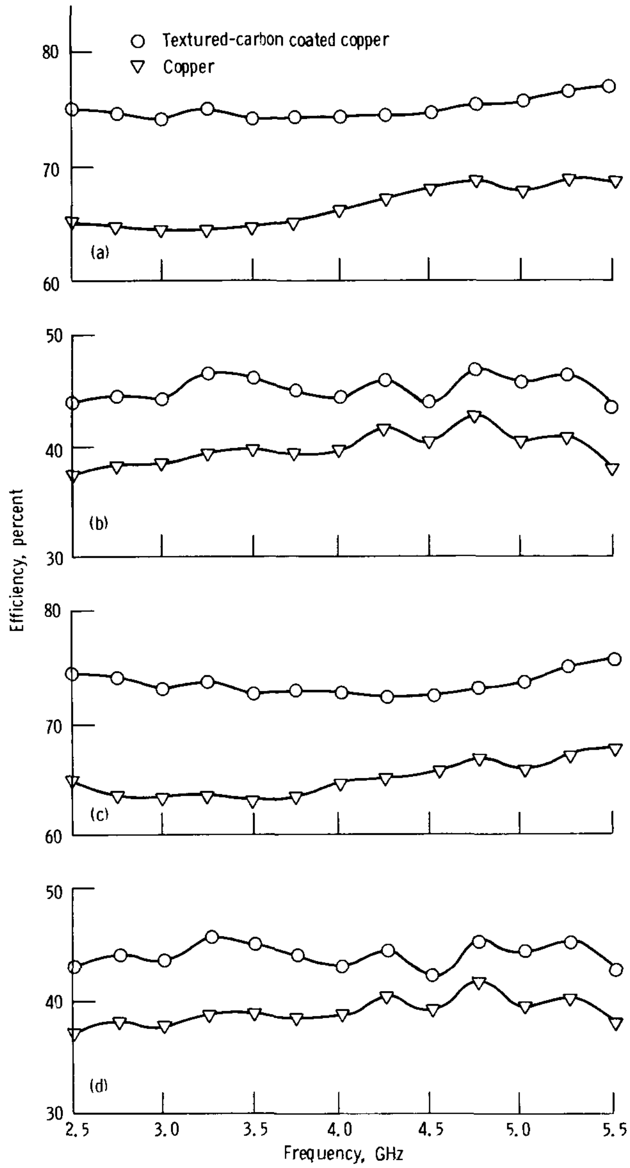
(b) MDC 3.

Figure 6.—Charge trajectories, equipotential lines, MDC geometry, and applied potentials in four-stage depressed collectors. TWT's operating at saturation.

Experimental Results—VA 101 and MDC 1

TWT-MDC Performance

The collector and overall efficiencies as functions of frequency at saturation for the textured-carbon-coated copper and copper electrode versions of MDC 1 are shown in figure 7 for the four- and three-stage versions of MDC 1. The average tube and collector performance across the operating band at saturation is summarized in table III. Using textured carbon-coated copper electrodes in place of copper electrodes improved overall efficiency 14 and 13 percent for the four- and three-stage collectors, respectively. Collector efficiencies improved 13 percent for both the four-and three-stage collectors. The performance of the textured-carbon-coated copper surface compared favorably with that of the other forms of carbon reported in reference 5. However, as discussed in reference 5 for the case of the textured isotropic graphite version of MDC 1, electron microscope examinations of the textured-carbon-coated copper electrode surfaces also indicated less than optimum texturing of large areas of the electrodes,



(a) Four-stage MDC; collector efficiency.
(b) Four-stage MDC; overall efficiency.
(c) Three-stage MDC; collector efficiency.
(d) Three-stage MDC; overall efficiency.

Figure 7.—Collector and overall efficiencies as function of frequency at saturation for VA 101 and MDC 1 (optimized at saturation at 4.75 GHz).

as compared to small flat samples. Consequently, when techniques for applying uniform, high-quality textured carbon coatings to MDC electrodes of complex shapes are perfected, the performance can be expected to improve slightly.

Short-Term Surface Stability Test

The test, performed at a duty cycle of 25 percent, consisted of the following:

(1) 515 hr of operation at saturation at 4.25 GHz
(2) 100 hr of operation with the dc beam

TABLE III.—SUMMARY OF AVERAGE TWT VA 101 AND MDC 1 PERFORMANCE ACROSS 2.5- TO 5.5-GHz OPERATING BAND AT SATURATION

(a) Four-stage collector

MDC electrode characteristics	RF efficiency of TWT, η_{RF}, percent	TWT overall efficiency, η_{ov}, percent	Collector efficiency, η_{col}, percent
Textured carbon on copper	21.3	45.3	75.1
Copper	21.1	39.9	66.5

(b) Three-stage collector

MDC electrode characteristics	RF frequency of TWT, η_{RF}, percent	TWT overall efficiency, η_{ov}, percent	Collector efficiency, η_{col}, percent
Textured carbon on copper	21.2	44.1	73.5
Copper	21.1	39.1	64.9

TABLE IV.—TYPICAL TWT-MDC OPERATING CONDITIONS DURING SHORT-TERM SURFACE STABILITY TEST WITH VA 101 AND MDC 1

	Saturation at 4.25 GHz	dc beam
Total RF output power, P_{RF}, W	820	0
Total body current, I_G, mA	60	13
Current to collector 1, I_{e1}, mA	156	11
Current to collector 2, I_{e2}, mA	198	13
Current to collector 3, I_{e3}, mA	182	564
Current to collector 4, I_{e4}, mA	5	0
Duty cycle, percent	25	25

(3) A brief performance evaluation at saturation at 4.25 GHz subsequent to the dc beam test

The test was performed at slightly reduced MDC operating voltages (reduced from the optimum values for operation at saturation at 4.75 GHz) to reduce the backstreaming losses to the TWT body. The operating voltages, with respect to ground, were −6.20, −5.10, −3.00, and −2.40 kV (down from −6.20, −5.20, 3.16, and −2.62 kV). Typical TWT-MDC operating conditions for the two parts of the test are shown in table IV. An estimate of the peak power dissipated on the electrodes during the RF test can be made from the measured electrode thermal dissipations with the copper electrode version of the MDC (ref. 5). These values, along with the electrode voltages and currents, are shown in table V. The dissipated electrode powers for the carbon-black-coated copper electrode version of MDC 1 are also shown in table V. (See ref. 8.) However, these values are less easily related to those for textured-carbon-coated copper because operating

TABLE V.—MDC OPERATING VOLTAGES, CURRENTS, AND DISSIPATED POWERS FOR MDC 1 and VA 101 OPERATING AT SATURATION AT 4.25 GHz (refs. 5 and 8)

(a) Copper

Collector electrode	Operating voltage[a], kV	Current, mA	Dissipated power, W
1	−2.55	120	140
2	−2.90	210	285
3	−4.94	181	224
4	−6.21	−7	6

(b) Carbon black electrode surfaces

Collector electrode	Operating voltage[a], kV	Current, mA	Dissipated power, W
1	−2.65	166	122
2	−3.24	181	168
3	−5.25	186	184
4	−6.20	3	61

[a]With respect to ground.

TABLE VI.—MDC 3 OPERATING VOLTAGES DURING EXTENDED CW TEST

Electrode	Nominal voltage[a], kV	Reduced voltage[a], kV	dc beam case voltage[a], kV
0	0	0	0
1	−5.50	−5.40	−5.50
2	−6.91	−6.91	−6.91
3	−9.10	−8.90	−8.80
4	−9.95	−9.95	−9.95

[a]With respect to ground.

voltages were somewhat different and there was some radiative heat transfer between the electrodes, notably from electrode 3 to electrode 4.

Electrode dissipation during the dc beam test (discussed later) can be estimated from $(V_{en})I_{en}$. Based on this equation, the peak dissipation was at least 620 W on electrode 3, approximately 40 W on electrodes 1 and 2, and 0 W on electrode 4.

A number of TWT shutdowns and some relatively small (of the order of 1 or 2 percent) tube performance changes were observed during the RF test. All things considered, no degradation in MDC performance (based on periodic measurements of the collector currents and recovered power) was observed during the 515-hr test.

Based on this observation, it was decided to proceed to the test with the dc beam, where the thermal dissipation on electrode 3 would be more than doubled. No degradation whatever in the collector performance was observed during the 100 hr of operation with the dc beam. Subsequent brief operation at saturation at 4.25 GHz confirmed that there was no degradation in MDC performance. Scanning electron microscope examination of the electrode surfaces following disassembly of the MDC confirmed that there was good stability of the electrode surfaces.

Experimental Results—T MEC 103 and MDC 3

With the TWT operating at saturation at 6.4 GHz, the TWT-MDC was brought up to CW operation in about 6 hr. During the pulsed operation at increasing duty cycle, a considerable RF power fade was observed. Total RF output power P_{RF} dropped from about 520 W at a duty cycle of 10 percent to 460 W at a duty cycle of 100 percent. Because of this power fade it was decided to limit operation to 6.4 GHz and not to attempt operation across the 4.8- to 9.6-GHz operating band. This decision was based on measurements of P_{body} as a function of frequency for the previous test with an undepressed collector, which showed rather high values of P_{body} at a number of frequencies in the operating band. The MDC spike length and refocusing system operating conditions, which had been previously optimized at low-duty cycle, were slightly readjusted (optimized) for CW operation at saturation at 6.4 GHz. Thereafter, these operating conditions were kept constant for the duration of the test. The first half of the RF test was conducted using MDC operating voltages (see the nominal voltages listed in table VI) optimized at the same time as the other variables.

Total RF output power P_{RF} increased steadily during the first 100 hr of CW operation (and more slowly thereafter) and reached a steady level approximately 150 hr into the CW test. Because the TWT gain was also increasing, the TWT was operated slightly below saturation (within a few percent in P_{RF}) to prevent overdriving the TWT during unattended operation. Two operating conditions, at RF input powers of 10 and 12.5 mW, were selected for monitoring MDC performance.

After 400 to 500 hr of CW operation it was noticed that the magnitude of V_{e3} (and to a lesser extent V_{e1}) had an affect on P_{RF}. Operating at the reduced voltages given in table VI increased P_{RF} by 7 to 8 W and decreased I_G by 2 to 3 mA. A small change in the TWT gain was also observed. The input needed for saturation dropped from 15 to 12.5 mW. Thereafter, it was decided to operate the MDC mostly at this set of reduced voltages.

The RF CW test, which lasted 1025 hr, was conducted almost entirely at four operating conditions, which are given in table VII. For the case of the nominal MDC voltages, performance was monitored for the entire duration of the test; for the case of the reduced MDC voltages, however,

TABLE VII.—TYPICAL T MEC 103-MDC 3 OPERATING CONDITIONS DURING EXTENDED CW TEST

[Beam current, I_0 = 0.40 A; cathode potential, V_0 = −9.95 kV; operating frequency, f = 6.4 GHz.]

Operating conditions	Radiofrequency (RF) input power =12.5 mW		Radiofrequency (RF) input power =10 mW		Radiofrequency (RF) input power =0
	Nominal MDC voltage	Reduced MDC voltage	Nominal MDC voltage	Reduced MDC voltage	dc beam case voltage
Total RF output power, P_{RF}, W	510	518	496	503	0
Total body current, I_G, mA	21	19	21	18	6
Current to collector 0, I_{e0}, mA	8	6	8	7	1
Current to collector 1, I_{e1}, mA	155	160	151	155	15
Current to collector 2, I_{e2}, mA	68	64	59	59	21
Current to collector 3, I_{e3}, mA	145	148	157	158	356
Current to collector 4, I_{e4}, mA	4	3	5	3	0
Total MDC dissipation, W	520	565	510	545	555

TABLE VIII.—MDC OPERATING VOLTAGES, CURRENTS, AND DISSIPATED POWERS FOR MDC 3 AND T MEC 103 OPERATING AT 6.4 GHz

(a) Carbon black electrode surface

Collector electrode	Operating voltage[a], kV	Current, mA	Dissipated power, W
0	0	5	36
1	−5.62	153	154
2	−7.02	75	119
3	−9.16	146	146
4	−9.95	4	40

(b) Textured carbon on copper (Radiofrequency (RF) input power, P_{in} = 12.5 mW; nominal voltages)

Collector electrode	Operating voltage[a], kV	Current, mA	Dissipated power, W
0	0	8	[b]36
1	−5.5	155	[b]173
2	−6.91	68	[b]119
3	−9.10	145	[b]189
4	−9.95	4	[b]9

(c) Textured carbon on copper (Radiofrequency (RF) input power, P_{in} = 12.5 mW; reduced MDC voltages)

Collector electrode	Operating voltage[a], kV	Current, mA	Dissipated power, W
0	0	8	[b]36
1	−5.50	160	[b]189
2	−6.91	64	[b]119
3	−8.90	148	[b]219
4	−9.95	3	[b]9

[a]With respect to ground.
[b]Estimated value based on adjustment for differences in operating voltage and radiation from electrodes 3 to 4.

performance was monitored only over the last half of the test. During the first 150 hr of the test, when P_{RF} was changing, changes in some of the collector currents and in the recovered power were observed. Based on scanning electron microscope examinations of selected areas of the electrode surfaces before and after operation with the TWT (discussed later) it was possible to attribute these changes entirely to TWT performance changes.

During the last 875 hr of the RF test no degradation in the collector performance was observed. The collector current distributions at the four operating conditions were constant with time. (They were within the accuracy of the measurements, with allowance for small up and down changes in TWT performance due to unplanned shutdowns.)

Estimates of the thermal power dissipated on each electrode for the nominal and reduced sets of MDC voltages at an input drive power of 12.5 mW are shown in table VIII. These estimates were based on the measured values (from ref. 9) for carbon black electrode surfaces (also shown in table VIII), and include adjustments for radiation from electrode 3 to 4 (for carbon black only) and for slightly different operating voltages. For input drive powers of 10 mW, the total MDC dissipation is slightly lower (table VII); dissipation on electrode 3 would be expected to be slightly (< 10 percent) higher and that on electrodes 2 and 1 slightly lower because of changes in the MDC current distribution.

When no degradation in the collector performance was observed after more than 1000 hr of RF operation, the test with the dc beam was started. Previously, very limited (< 1 hr total) operation with the dc beam had indicated that the TWT oscillated when the MDC was operated at either the nominal or the reduced sets of voltages. It was found, however, that at the operating voltages shown in table VI (labeled "dc beam case voltages") the oscillation disappeared. Consequently, the entire dc beam test was conducted at this set of MDC voltages. The thermal dissipation on each electrode can be estimated from $(V_{en})(I_{en})$. These values are 0, 410, 65, 66, and 12 W for electrodes 4 to 0, respectively.

No degradation in MDC performance was observed during the dc beam test; the current to electrode 3 stayed constant to within a small fraction of a percent. Near the end of the dc beam test the TWT-MDC performance was remeasured for the four RF operating conditions shown in table VII. The results confirmed that no degradation in MDC performance had occurred. Subsequently the MDC was disassembled and the electrode surfaces were reexamined with a scanning electron microscope. A comparison of the surface characteristics before and after operation with the TWT showed no readily discernable changes of the surface morphology.

Concluding Remarks

The textured-carbon-coated copper MDC electrode surfaces produced a 13- to 14-percent improvement in the TWT overall efficiency, as compared to the same TWT operated with an identical copper collector. The extended CW test performed with a typical ECM TWT and a small-size MDC showed no degradation in collector performance (and, therefore, good electrode surface stability) after more than 1000 hr of RF operation and 500 hr of operation with the dc beam. These results should be of considerable interest to anyone concerned with enhancing tube efficiency. The energy and current densities in the MDC's tested were considerably higher than those encountered in typical space TWT's.

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National Aeronautics and Space Administration
Cleveland, Ohio, September 4, 1986

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16. Abstract

Performance of multistage depressed collectors (MDC's) using novel textured carbon on copper substrate electrode surfaces was evaluated in conjunction with medium-power traveling wave tubes (TWT's). MDC and TWT overall efficiencies for these novel electrodes were measured and compared with those obtained with the same TWT and a copper electrode MDC of identical design. Long-term stability of the carbon-coated copper electrode surfaces was investigated by periodic evaluation of TWT-MDC performance over an extended period of continuous wave (CW) operation. Application of textured carbon coating on copper MDC electrode surfaces produced a 13-percent improvement in both MDC and TWT overall efficiencies for the TWT-MDC tested. During 1600 hr of CW operation with a medium power TWT, no significant changes in MDC performance were observed. This indicated good stability of the textured carbon electrode surfaces. This stability was confirmed by scanning electron microscope examinations of the electrode surfaces before assembly of the MDC and after completion of the test program.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Carbon on copper electrodes; Multistage depressed collector; Traveling wave amplifier; Secondary electron emission; Traveling wave tube	Unclassified – unlimited STAR Category 33

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