Design and Development of High Efficiency 140W Space TWT with Graphite Collector

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Abstract. 4-stage graphite collector assembly has been designed and developed for a 140W Ku-band space TWT to achieve the collector efficiency more than 80%. The UHV compatible, high density, copper impregnated POCO graphite (DFP-1C) was used to fabricate the four collector electrodes of the 4-stage depressed collector. Copper impregnated graphite material is used for the collector electrodes because of its low secondary electron emission coefficient, high thermal and electrical conductivities, easy machining and brazing, low thermal expansion coefficient and low weight. The graphite material was characterized for the UHV compatibility. The collector electrodes were precisely fabricated by careful machining, and technology was developed for brazing of graphite electrodes with high voltage alumina insulators. Complete TWT with four-stage graphite collector was developed and 140W output power at gain more than 55 dB was achieved. The TWT was pumped from both the gun and the collector ends.

1.0 Introduction

Travelling Wave Tube (TWT) [1] is a ultra high vacuum microwave device. The complete TWT with electron gun, helix slow-wave structure (SWS), input/output couplers, periodic-permanent magnet (PPM) focusing and radiation-cooled 4-stage depressed collector, is shown in Fig.1. The TWT is being developed for the Ku-band satellite transponders for amplification of low RF signals on board satellite to 140W output power with overall efficiency more than 60%, gain more than 55dB over the frequency band of 10.9 to 11.7GHz. The 4-stage high efficiency graphite collector assembly has been used with the TWT for the first time in our country. Overall efficiency more than 60% is a prime concern along with the high reliability and long life for the space traveling wave tubes.
2.0 Selection of graphite material

Multistage depressed collector (MDC) [2] recovers part of the kinetic energy of the spent electron beam. The spent electron beam entering into the collector has significant energy that is to be recovered by collecting the beam on different electrodes set at reduced potentials. As shown in Fig.2, 4-stage collector is designed for the 140W TWT to achieve collector efficiency more than 80% including secondary electron emission from collector electrodes. For a 140W TWT, the collector dissipation is of the order of 50W.

![Fig. 1: Ku Band 140 W Space TWT with 4-stage collector](image)

![Fig. 2: Primary (blue) and secondary (green) electron trajectories in a 4-stage depressed collector](image)

The efficiency of MDC is adversely affected by the secondary electron emission (δ) characteristics of the collector electrodes. To achieve higher collector efficiency, the material of MDC electrode must have low secondary electron emission coefficient. The choice of materials [3] for the fabrication of MDC is critically important from the viewpoint of low secondary electron emission coefficient, UHV compatibility and thermal conductivity. Because of good mechanical, electrical and thermal properties, copper has been widely used for collector electrode. However, it has a relatively higher secondary electron emission coefficient of the order of 1.3 to 2.0. For achieving low δ values, the techniques used are either coating of carbon or TiC on copper electrodes. TiC coating has a disadvantage of low electrical conductivity. Carbon-coating has good thermal and electrical conductivity. By using carbon coating, the SEE coefficient can be reduced to a low value of 0.4 to 0.5. However, there is a problem in achieving long life with this type of coating on copper electrodes as the coating may deplete with time. Therefore, for long-life application as desired for a space TWT, in place of copper, graphite material has been selected for the collector electrodes. Graphite has relatively low secondary electron emission coefficient (≈0.70), but it has porosity and relatively low electrical and thermal conductivity.

Copper impregnated POCO graphite (DFP-1C) [4] was selected to fabricate the collector electrodes for improving the collector performance. POCO (DFP-1C) material has low secondary electron emission coefficient, high thermal and electrical conductivities, easy machining, low thermal expansion coefficient and low weight. Brazing of this material (DFP-1C) is also easy with this material itself and with the metallized alumina high voltage insulators. This graphite material was characterized for the UHV compatibility and minimum out gassing properties. The collector electrodes
were precisely fabricated by careful machining, and technology was developed for brazing of graphite electrodes with high voltage alumina insulators. X-rays studies have been carried out to ensure that the graphite material is free of micro cracks, after its machining, firing and its brazing with metallized ceramic insulators. Fig.2 (a) shows four graphite collector electrodes brazed with the metallised alumina insulators, for a 4-stage collector assembly, as shown in Fig. 2(b). Suitable technology was developed for successful brazing of graphite collector electrodes with metallized high voltage alumina insulators both in vacuum as well as in hydrogen and (H$_2$-N$_2$) atmosphere.

![Fig. 2(a): Graphite electrodes for 4-stage depressed collector](image1)

![Fig.2 (b): Multistage depressed collector assembly](image2)

Ion texturing inside surface of collector electrodes is required to reduce further the secondary electron emission of graphite electrodes to the lowest desirable level of 0.2-0.3. Ion texturing of depth 5 to 6 microns with inter-spacing of 6-10 microns is needed which is possible by Argon-ion bombardment of the graphite electrodes. SEE emission was measured using Auger system [6].

### 3.0 UHV compatibility of Graphite Electrodes

Completely fabricated 4-stage collector assembly with POCO graphite electrodes and feed-through was mounted in a 35CFF ‘TEE’ and vacuum processed on Varian UHV system, with Sputter ion pump of 120 l/s. The assembly was baked up to 550°C for 20 hrs. The ultimate IG vacuum better than 2x10$^{-8}$ mbar was achieved. RGA analysis using a SUPA-VAC Residual Gas Analyzer [6] was done at various stages, before baking, at 550°C, and after the baking, for partial pressure of hydrogen, carbon, nitrogen, carbon mono oxide and carbon dioxide. The partial pressures of above elements have significantly reduced after the baking, as shown in the table-3. No unusual degassing from graphite has been observed as seen by noting partial pressures at different stages of prolonged baking. In view of the residual gas analysis carried out on POCO graphite sample and subsequently on the graphite collector assembly, the same is found acceptable for a UHV TWTs. Long life analysis is required for ascertaining the use of POCO graphite for space TWT.
Table 3: Residual gas analysis of Collector Assembly mounted on UHV System

| Element | Before baking (Partial pressure in mbar) | At 550°C holding For 30 hrs (Partial pressure in mbar) | After complete baking (Partial pressure in mbar) |
|---------|----------------------------------------|------------------------------------------------------|---------------------------------------------|
| H₂      | 1.6x10⁻⁶                               | 9.6x10⁻⁸                                            | 1.0x10⁻⁸                                   |
| He      | 2.9x10⁻⁸                               | 7.4x10⁻⁹                                            | 0.2x10⁻⁹                                   |
| C       | 1.2x10⁻⁸                               | 3.9x10⁻⁹                                            | 2.4x10⁻¹⁰                                  |
| N₂      | 1.4x10⁻⁸                               | 4.2x10⁻⁹                                            | 1.2x10⁻¹⁰                                  |
| O₂      | 5.2x10⁻⁸                               | 1.6x10⁻⁸                                            | 7.5x10⁻¹⁰                                  |
| CO      | 1.1x10⁻⁶                               | 7.6x10⁻⁸                                            | 5.5x10⁻⁹                                   |
| CO₂     | 5.8x10⁻⁸                               | 2.4x10⁻⁸                                            | 1.0x10⁻⁹                                   |

4.0 Assembly of Complete TWT, UHV Processing, and testing

Complete TWT with 4-stage graphite electrode collector [7] was assembled. To study the amount of degassing during processing and hot RF testing, the TWT with graphite collector was fabricated using 2l/s appendage pumps at both the gun and the collector ends, as shown in Fig.3. The TWT was connected to the UHV processing system from the gun end and it was vacuum processed up to 450 deg. C for more than 100 hours. The RGA analysis was done at different stages of UHV processing. No additional residual or contaminations from the graphite collector was observed. The partial pressure of different constituents including the carbon dioxide and carbon monoxide were finally found less than 1x10⁻⁸ torr at 400 deg. C. The ultimate vacuum under cold condition was achieved better than 1x10⁻⁹ torr.

After completing vacuum processing of the TWT with graphite collector including cathode activation and cathode emission dip test, the hot RF testing was done keeping 2l/s appendage pumps ON at both the gun and the collector ends. Non-evaporable getter has also been used at gun end. No degassing was observed from the collector end during hot rf testing. The TWT output power was measured more than 140W, indicating no degradation in the TWT performance using graphite material for the collector electrodes. The detailed RF performance of the TWT with graphite collector is determined. Fig. 4(a) shows output power versus frequency and Fig.4(b) shows gain versus frequency for a 140W, 55dB gain Ku-band TWT. Complete packaged radiation-cooled Ku-band TWT is shown in Fig.5.

Fig. 3: Complete Ku-band TWT with 2l/s Appendage pumps on both gun and collector sides
Fig. 4(a): Experimental and simulated output power versus frequency for a Ku-band TWT

Fig. 4(b): Experimental and simulated gain versus frequency for a Ku-band TWT

Fig. 5: Complete packaged radiation-cooled Ku-band TWT
5.0 Conclusion

Complete TWT with four-stage graphite collector was developed and vacuum processed on UHV system at 450°C for 100 hours. During and after UHV processing the TWT, partial pressure of hydrogen, carbon, nitrogen, carbon monoxide and carbon dioxide were determined. No degassing after processing was found. Copper-impregnated POCO (DFP-1C) graphite was found compatible for an ultra-high-vacuum TWT. The 140W output power at gain more than 55 dB was achieved from the developed Ku-band graphite collector TWT.

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References:

1. V.Srivastava, et.al, Design of high Efficiency Space TWT, IETE Technical Review, March-April 1999, pp. 249-254.

2. T.K.Ghosh, et.al, Development of Graphite Collector Electrodes for High Efficiency Space TWTs, IVS Bulletin, June 2004.

3. J.P. Calame, D.K.Abe, Application of advanced material Technologies to Vacuum Electronic devices, Proceedings IEEE, May1999, pp 840-864.

4. R.G. Sheppard, D.M. Mathes, D.J. Bray, Properties and Characteristics of Graphite, POCO Graphite, Inc.

5. AK Chopra, RS Raju, SK Sharma, V Srivastava and SN Joshi, ‘Application of Auger Electron Spectroscopy for measurement of secondary electron emission coefficient’, DAE-BRNS Symposium on Electron Beam Technology and Applications (SEBTA-05), BARC, Mumbai, Oct.21-23, 2005,

6. V Srivastava, AK Sharma, SK Sharma, AK Chopra and SN Joshi, ‘Residual Gas Analysis of high density graphite for a high efficiency TWT’, IVSNS-2005 Symp., IPR Gandhinagar, Nov.16-18, 2005.

7. V Srivastava, SK Sharma, SS Budania, AK Chopra, SN Joshi, D Basu, R Sen and TK Ghosh, ‘Development of 4-stage graphite collector for High Efficiency TWTs’, 6th International Vacuum Electronics Conference (IVEC-2005), European Space Agency, Noordwijk, April 20-22, 2005.