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HIGH GRADIENT ELECTRON GUNS*

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Abstract

Experiments have been conducted to determine peak operating gradients attainable in thermionic electron guns. These tests are part of a study of high-current-density, long-life cathodes suitable for use in high power klystrons. We also investigated the use of chromium oxide coating as a means of inhibiting electronic breakdown across the focus electrode anode gap. Field gradients in excess of 280 kV/cm have been achieved for a gun operating at 240 kV with a beam current of 228 A, at pulse widths of the order of 1 μs.

Introduction

Klystrons presently being considered for the next generation of linear colliders must be capable of providing powers in excess of 100 MW at pulse widths of several hundred nanoseconds at approximately 11.4 GHz. This will require an electron gun which operates with high electric field gradients and a high-current-density, long-life cathode. To test these limits, a beam diode was designed and constructed.

Device Design

The beam diode gun uses a conventional Pierce gun geometry. It was constructed from a standard SLAC 5045 klystron gun and was modified to include flanges that allowed the device to be easily separated and adjusted as experimental testing required. A cross section of the beam diode is shown in Fig. 1. The assembled device is shown in Fig. 2.

The 3.2 cm diameter cathodes used for this device were standard M-type dispenser cathodes, fabricated from a porous tungsten matrix and impregnated with a barium-rich compound. The first experiment had a cathode coated at Spectra-Mat, Inc., with an osmium-tungsten coating. The cathode used in the second experiment was coated at Varian Associates by sputtering a thin layer of osmium-ruthenium-tungsten onto the cathode surface. The purpose of these coatings was to reduce the effective work function of the cathode, thus allowing maximum electron emission at the lowest possible temperature.[1]

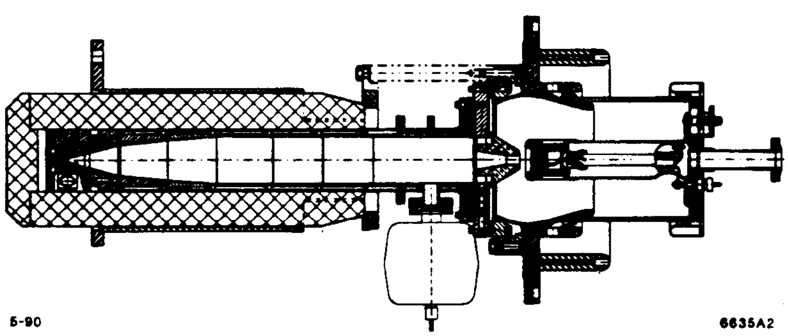

Fig. 1. Cross section of the beam diode.

The focus electrode was made from 317L vacuum-melted stainless steel. It was fired to a temperature of 980°C in a wet hydrogen atmosphere. This process, sometimes referred to as "greening," results in a surface layer of predominately chromium oxide, which is believed to improve the breakdown resistance of electrodes. The anode and collector were made of oxygen-free, electronic-grade copper.

The focus electrode and the cathode experienced thermal expansion during actual operating conditions. Measurements found that the focus electrode moved .056 inches closer to the anode when the cathode was operated at 1180°C. It was this anode-to-focus electrode geometry that was used to calculate the peak electric field gradients.

After assembly of the diode, it was vacuum-baked at 550°C for several days. The base pressure at the end of the bake was in the 10^{-9} Torr range. This pressure did not noticeably increase during testing even when the cathode was heated to almost 1200°C_B.

The modulator used to test the beam diode was capable of providing a beam voltage up to 400 kV. Perveance was 1.9×10^{-6}. For the voltage breakdown studies, the beam pulse width was converted from a minimum of 1 μs to over 5 μs by reconfiguring the modulator.

Results

The primary purpose of this experiment was to find the maximum electric field gradients sustainable between the focus electrode and anode. We were also interested in observing accelerated cathode degradation when run at high current densities.

In the first diode, the cathode was operated in the fully space-charge limited region at a cathode temperature of 1130°C_B and a current density of 17 A/cm^2. Maximum focus electrode electric field gradient was 240 kV/cm. Beam voltage could not be increased above

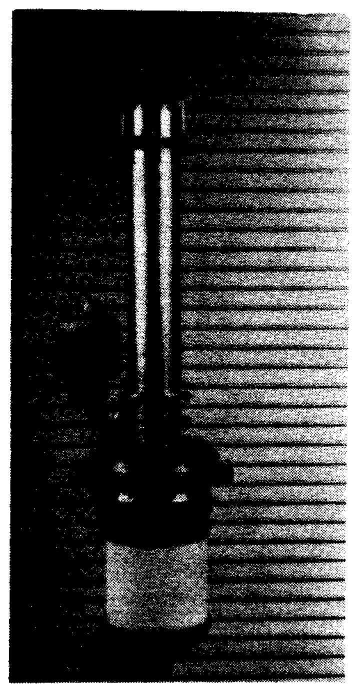

Fig. 2. Assembled beam diode.

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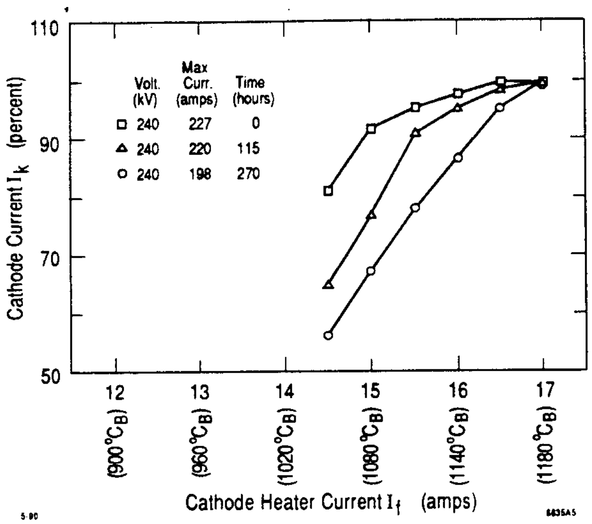

Fig. 3. Miram curves as a function of time for cathode operating at 17 A.

200 kV due to excessive arcing. After disassembly, evaluation of the anode region showed evidence of beam interception, which was substantiated by additional computer beam simulation.

For the second experiment the anode region of the diode was reworked and the Varian coated cathode was installed. With a beam pulse width of 2.2 μs, a heater current of 16.5 A (1160°C_B), and a current density of 28 A/cm^2, the beam voltage reached 240 kV, with only minimal voltage breakdown. This corresponds to a focus electrode electric field gradient of 290 kV/cm. This gradient is considered to be sufficient for future 100 MW klystron guns.

Subsequently, the heater current was increased to 17 A (1180°C_B). The mean current density of the cathode dropped to 24 A/cm^2 after 270 hours. This cathode degradation is graphically represented in the Miram curves[2] shown in Fig. 3. The diminishing sharpness of the knee as a function of time indicates that the effective work function distribution has expanded and that higher cathode temperatures will be required to achieve space charge limited operation.

The next experiment was to determine the maximum electric field gradients attainable at larger pulse lengths. The modulator was adjusted to provide a 5 μs pulse length. First signs of breakdown were seen at 300 kV which corresponded to a peak electric field gradient of 360 kV/cm. The microperveance was 1.4 by this time, due to further cathode degradation. The peak current was 228 A, and the current density was 28 A/cm^2.

The modulator was reconfigured to run at 1 μs. Stable operation was observed up to 350 kV. At this voltage the peak electric field was 420 kV/cm, the mircoperveance was 1.1, and the current density was 29 A/cm^2. The voltage was raised to 369 kV, where faulting was observed. This excessive faulting prevented further operation. The modulator was returned to its initial pulse width of 2.2 μs, but could not be run stably above 275 kV, indicating the arcing had damage the electrode surface. The beam voltage and beam current pulse shapes for the 5 μs and 1 μs are shown in Fig. 4.

Comparison of the data points observed in this experiment with those reported by Staprans[3] can be seen in Fig. 5. The Staprans article suggests that for the anode to focus electrode spacing used in this device (1.0 cm), an expected voltage breakdown level should be in the range of 160 kV to 180 kV instead of the 270 to 350 kV range observed in this study.

These voltage breakdown studies were done near the end of the cathode life, as shown by the drop in microperveance from 1.93 to 1.10. Autopsy of the diode after completion of these tests showed a heavy barium deposit on the anode and

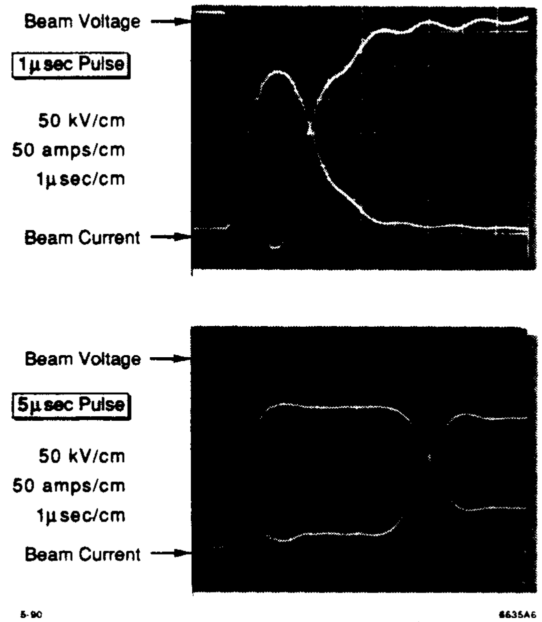

Fig. 4. Beam voltage and beam current pulse shapes.

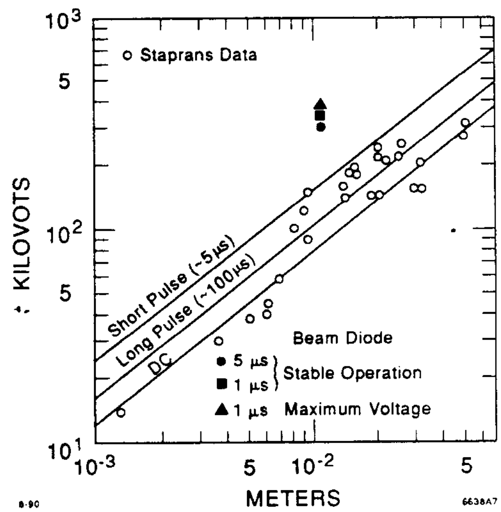

Fig. 5. Comparison of Staprans' data[3] with present work.

focus electrode, which is typical for end of cathode life conditions. It is believed that this barium buildup contributed to the voltage breakdown. This is evidenced by the multiple arcing spots on the anode and focus electrode, where the barium deposits are thickest.

Conclusions

Current densities up to 28 A/cm^2 were obtained, although the lifetime was short due to the high operating temperature.

It was determined that voltage gradients up to 420 kV/cm for a pulse width of 1 μs and up to 360 kV/cm for a 5 μs pulse width are sustainable.

Additional long-term tests are planned at lower cathode temperatures to determine cathode lifetime as a function of current density.

References

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[3] A. Staprans, "Electron Gun Breakdown," High Voltage Workshop, Monterey, 1985.