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HIGH CURRENT DENSITY PULSED CATHODE EXPERIMENTS AT SLAC*

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ABSTRACT

A 1.9 microperveance beam diode has been constructed to test high current density cathodes for use in klystrons. Several standard and specially coated dispenser cathodes are being tested. Results of tests to date show average cathode current densities in excess of 25 amps/cm, and maximum electric field gradients of more than 450 kV/cm. for pulses of the order of 1 μsec.

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1. BACKGROUND

Design studies for the next linear collider (NLC) indicate a need for structures capable of accelerating electrons with gradients of 100 MeV/meter. The type of power source envisioned for this program will deliver 0.1-I GW of RF power at a frequency of 11 GHz to these structures. Common to some of these power sources is the need for a high current density cathode to provide the required beam energy. In order to explore the limits of current density from thermionic emitters, and also to investigate the high E field gradients that are needed to support cathode high current densities, a special beam diode was constructed at Stanford Linear Accelerator Center (SLAC) and matched to available SLAC modulators.

2. CATHODE DESIGNS

The literature reports on a variety of semi-exotic cathode designs and materials that are capable of high-current density operation. While some of these ideas, with development, might be useful for X-band klystron beam generation, it was the object of this experimental study to explore the limits of conventional Pierce geometry and dispenser cathode technology. Small variations such as special cathode coatings and chrome oxide coatings (Greening) of electrodes were added to increase the limits of cathode emission and voltage breakdown.

Cathode lifetime is critically dependent on its operating temperature. Several different ideas are therefore in use to reduce the effective cathode work function in order that sufficient electron emission occurs at the lowest possible temperature. Standard methods used for barium impregnated tungsten cathodes are the "M"-type and "scandated" cathodes. hl-type cathodes involve coating the surface of barium impregnated tungsten with an alloy of the platinum group of elements, usually osmium, to lower the surface work function. Scandated cathodes have a small percentage of scandia added to the impregnant mixture during manufacture. Both types of cathodes permit operation at lower temperatures. Scandated cathodes are believed to be somewhat more robust under ion bombardment than M-type cathodes because the scandia is distributed throughout the cathode volume.[1] It has the disadvantage that the "knee" in the characteristic emission curve (T-L curve) is less pronounced, so that the changeover from temperature-limited to space-charge-limited operation is much more gradual. The production and operation of S-band klystrons for SLC operation has given us extensive

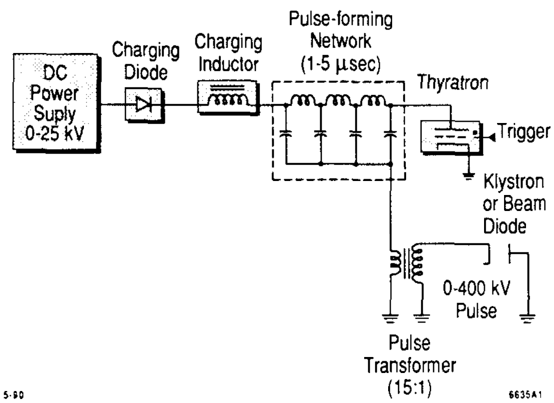

Figure 1: Block diagram of the test setup.

experience with Scandated dispenser cathodes operating at 7 amps/cm^2. These cathodes operate below 1,000°C, and routinely achieve lifetimes in excess of 25,000 hours.

A third type of cathode, currently being tested by Varian, is a variant of the M-type cathode and consists of a sputtered coating of W/Os on a standard Tungsten cathode.' It is claimed that this results in enhanced emission at lower temperature.

We are currently performing tests on these cathode types to determine their lifetime characteristics under high cathode-current density conditions. The tests reported in this paper have been made with a Varian coated cathode.

3. THE BEAM DIODE

The diameter of the test cathodes, 3.18 cm, was chosen so that an experimental beam diode could be constructed to match the parameters of existing modulators in the SLAC Klystron test laboratory. The beam voltage for a perveance 1.9 μperv diode could be run up to 400 kV in 1 μsec pulses. The block diagram of the test modulator is shown in fig. 1. By changing the number of capacitors and the tuning of the pulse forming network, the beam pulse width can be changed from a minimum of 1 μsec to over 5 μsec. The gun body of the SLC (5045) klystron provided an ideal high-voltage, high-vacuum structure to contain the experimental cathode, focus electrode, anode structure. A standard klystron collector provided a ready beam dump. A cross section of the resulting experimental beam diode is shown in fig. 2. A photograph of the diode is shown in fig. 3.

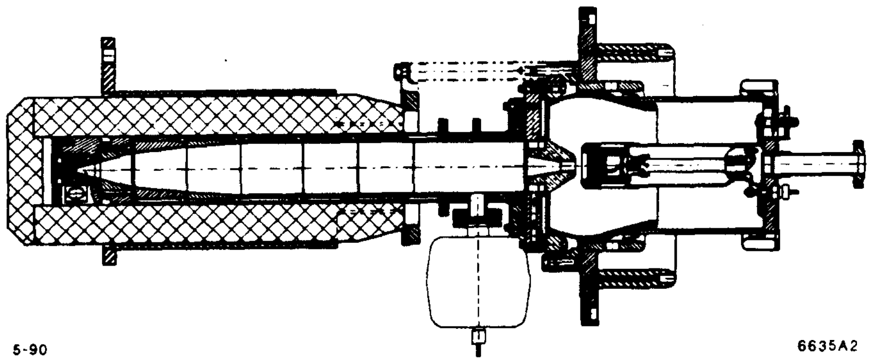

Figure 2: Cross section of the beam diode.

Figure 3: Assembled beam diode.

The diode is constructed to be easily disassembled and modified as required. As **with** all klystrons produced at SLAC, the beam diode structure undergoes an extended high temperature (550°C) bake each time it is opened and rebuilt. Base pressure in the baked diode is in the low 10^{-9} Torr range, and when the cathode is heated, even to very high temperatures. the pressure varies little from this level.

The first experiment made with this beam diode **was** conducted with a standard M-type dispenser cathode with a diameter of 32 mm. A space-charge limited current density of

17 $\mathrm{amps/cm^2}$ at a cathode temperature of 1130°C was achieved at a peak focus electrode E field gradient of 300 kV/cm. Voltage breakdown terminated this test at this level. Subsequent inspection of the anode, and further computer beam simulation confirmed that some of the beam was being intercepted on the copper anode.

The second experiment used a Varian coated cathode and produced the data presented in this paper. The object of this experiment was twofold. We wanted to explore the limits of maximum E field sustainable on the gun electrodes in an operating cathode environment. We also wanted to get an estimate of probable cathode lifetime as a function of peak current density, which in turn is dependent on cathode operating temperature.

4. VOLTAGE BREAKDOWN STUDIES

The beam diode configuration for this set of tests consisted of a Varian coated cathode. a stainless steel focus electrode which had been "Greened," and a copper anode. The Greening process is well known in the microwave tube industry and involves exposing stainless steel materials to an atmosphere of wet hydrogen in a brazing furnace. The effect is that some of the chromium in the stainless steel is oxidized, forming a tough, green-colored surface layer. This surface has been found to improve the breakdown resistance of electrodes.

The beam diode was baked to 550°C, which is normal SLAC processing, and installed in one of the test stands. Beam voltage was brought up slowly to 240 kV without experiencing any severe arcing. The vacuum was in the low 10^{-9} Torr range. The cathode heater was set at 17 amps corresponding to a cathode temperature of 1180°C. The diode was operated at these settings for 270 hours to accumulate accelerated life data as discussed in the next section. The focus electrode peak gradient under these conditions was 350 kV/cm. As cathode degradation became apparent, voltage breakdown experiments were initiated. The modulator was adjusted to maximum pulse length, 5 μsec, and the beam voltage was raised on the diode until the first signs of breakdown were observed. Figure 4 shows the beam voltage and beam current traces for both the 5 μsec operation and the subsequent I μsec operation. The beam diode operated at 300 kV with a microperveance of 1.4 which corresponds to a peak current of 212 amps and an average current density of 27 $\mathrm{amps/cm^2}$. This voltage was the breakdown threshold for the 5 μsec pulse, and corresponded to a peak field gradient of 440 kV/cm.

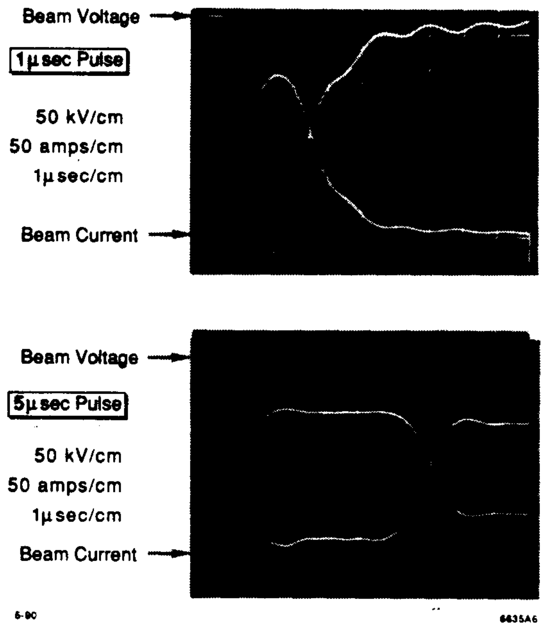

Figure 4: Beam voltage/current pulse shapes.

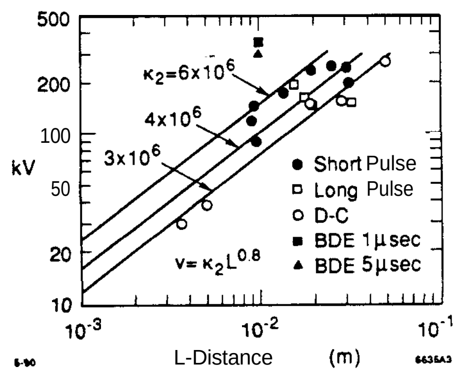

Figure 5: Comparison of Staprans (ref. 3) with present work.

The modulator was reconfigured for 1 μsec operation as shown in fig. 4, and the voltage was run up to breakdown limit again. At 1 μsec pulse width, stable operation was observed up to 350 kV, but faulting began to occur at 360 kV, became heavy at 369 kV, and after this faulting cycle, the beam diode would not operate above 250 kV indicating the faulting had damaged the electrodes. The 350 kV operation corresponded to a peak E field of 510 kV/cm. Figure 5 shows a curve of voltage breakdown limits based on various Varian tube operating

Figure 6: Cathode and focus electrode subassembly.

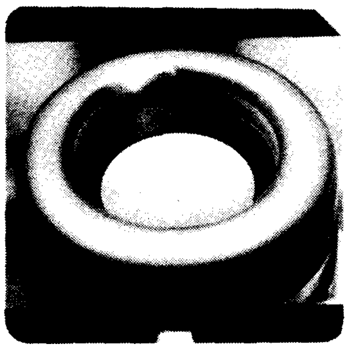

Figure 7: Focus electrode after completion of tests.

points. Breakdown voltages from this experiment are plotted on this curve.[3] The conclusion is that, with care in preparing and processing electrodes, voltage gradients of up to 450 kV/cm for pulse widths of 1 μsec may be possible in new design X-band klystrons.

It should be noted that these breakdown studies were conducted at the end of the accelerated life cycle of the Varian coated cathode when a good deal of barium had been deposited

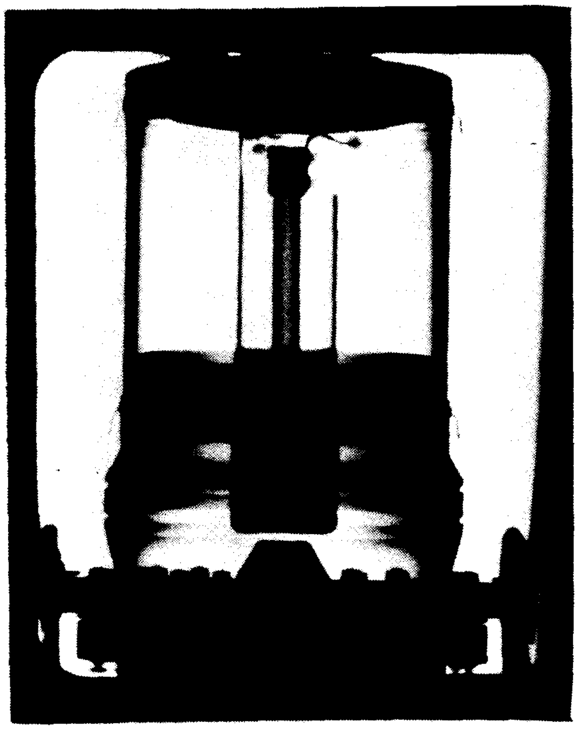

Figure 8: X-ray of beam diode.

on the copper anode. Figure 6 shows the cathode and Greened focus electrode after the diode was disassembled. Figure 7 shows a closeup of the focus electrode where the greening is etched away by the arcing. Figure 8 shows an x-ray of the beam diode cathode-anode region. Figure 9 shows the copper anode surface with evidence of buildup and multiple spots where this barium layer caused focus electrode to anode arcing.

5. CATHODE CURRENT DENSITY/LIFETIME STUDIES

The second object of the beam diode experiment was to investigate the lifetime of cathodes when operated at current densities of 20 to 30 amps/cm. The usual operating point for a cathode is a temperature just above the knee of the T-L curve. This is the point where minor variation of heater power no longer produces major changes in beam current. For space-charge limited operation, the longest cathode life can be expected at "knee." When the space charge limited currents of each curve are normalized to 100%, the curve of fig. 10 is the result. As can be seen from this curve, operation at high cathode current densities requires higher cathode temperatures to stay at the optimum point on the knee.

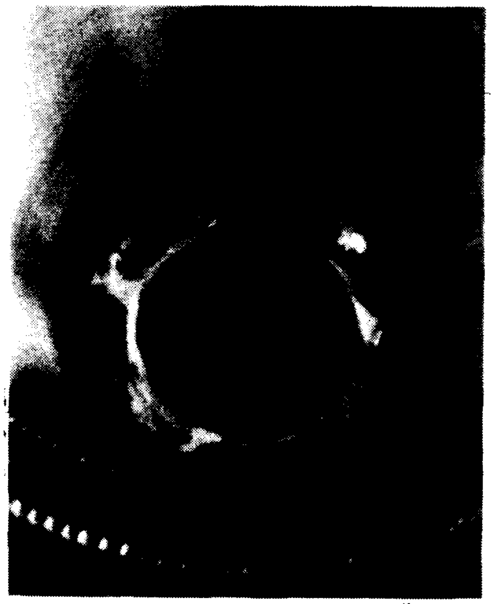

Figure 9: Anode after completion of tests.

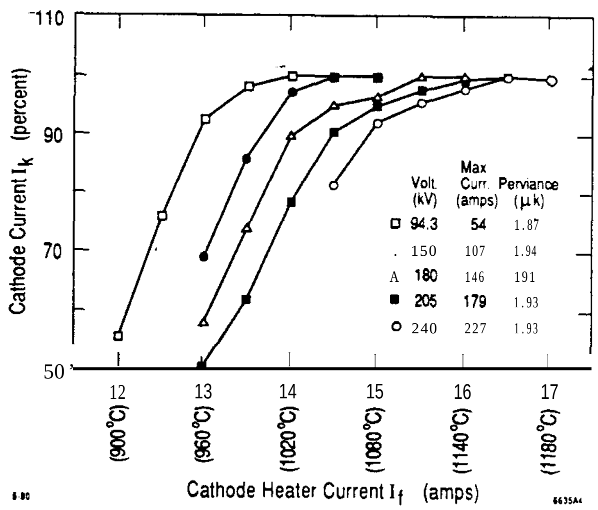

Figure 10: Normalized T-L curves (Miram curves) as a function of beam voltage.

The first beam diode was operated for 270 hours during which time the cathode emission degraded by over 20% at various operating temperatures. Figure 11 shows three T-L plots taken at the beginning, middle, and end of life of the test cathode. It will require further beam testing of cathodes to determine the expected cathode lifetime as a function of needed current

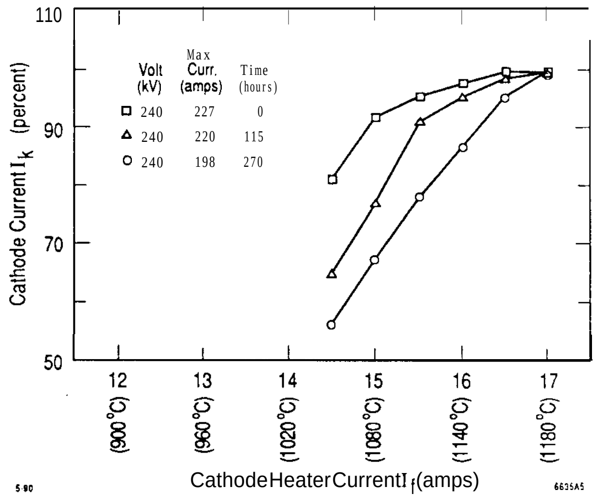

Figure 11: Normalized T-L curves (Miram curves) for cathode operating at 17 amps.

density. We expect to continue these cathode tests with several more samples operated for longer periods at lower temperatures to generate the cathode lifetime-current density data that will allow the selection of a cathode useful for high current density operation in an X-band klystron.

REFERENCES

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