A FERROELECTRIC CATHODE, ELECTRON GUN FOR HIGH POWER MICROWAVE RESEARCH *

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Abstract

A pulse modulator, previously described at the 1995 PAC meeting, has been reconfigured to improve the pulse shape at a slightly lower beam energy, but with a higher current (500kV,1kA). The device has been run at rated voltage and current into a resistive load for pulse durations in excess of 250ns and at $\sim 0.1Hz$ repetition rate. The modulator, which is designed for use in our high power microwave research program, has been coupled to an electron gun which uses a ferroelectric cathode and has been operated in this mode producing a 500kV, 200A electron beam. We report in this paper on the revised design and performance of the modulator and present preliminary data on the electron gun design and characteristics. The recessed ferroelectric cathode is located in the fringing field of a 3kG solenoidal magnetic field so that the emitted current will be compressed to about a ≤ 0.6cm diameter pencil beam, suitable for use in high power microwave amplifier experiments. The cathode emission is initiated by a 100ns, 2kV pulse inductively decoupled from the ground by a coaxial cable wound around the transformer core. The pulse transformer, which is driven by three pairs of plus/minus charged 5Ω pulselines, feeds a step-up transformer giving a matched output impedance of $\sim 500\Omega$. It is switched independently of the ferroelectric trigger to provide maximum operating flexibility. Results will be reported on all aspects of the system design and operation.

1 INTRODUCTION

As part of our high power microwave generation research program we are developing a low repetition rate modulator/electron gun. The modulator uses a ferrite core transformer the design of which is an evolution of a device previously reported in the PAC95 Conference [1]. We require a pulse with a flat top of order of or greater than 250ns at a voltage of 500kV and with a beam current of 200-500A, depending on the application. We have also been involved in the study of ferroelectric cathodes and plan to investigate their suitability for use as a high current density electron beam source. In the following sections we summarize the modifications made, since our last report, to the modulator and describe the implementation of the ferroelectric cathode. Our present gun experiments concentrate on extending the current-voltage characteristics of the ferroelectric to $\sim$ 500kV with a lesser effort made to generate a useful electron beam. Designs are in hand for the actual gun based on EGUN simulations. Up until the present we have generated a $\sim$ 420kV, 200A electron beam in a pulse with a relatively flat top of $\sim$250ns. The ferroelectric cathode, which is command triggered $\leq 2\mu$s before the diode voltage pulse, produces the 200A beam at an average current density of 75 A/cm^2.

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2 MODULATOR DESIGN MODIFICATIONS.

The modulator design, which was originally reported at the PAC95 meeting, has been run as either two 6:1 step up transformers operated in series or as a 12:1 step up transformer run with a single set of cores. The lower gain, compared to that reported at PAC95, was needed to reduce the rise time of the output pulse. In both configurations the system is now driven by three pairs of plus/minus 40kV charged 5Ω pulse lines and hence has an output impedance of $\sim$500 Ω. At the rated voltage the energy stored in the pulse lines is $\sim$ 300J. The modulator is switched by a command triggered pressurized gas switch. A shunt resistor (R$\geq$ 900Ω) is used to limit the voltage excursion if the diode current is not properly initiated. The shunt resistor is also used, together with a 10 kΩ gun voltage resistive monitor located along the insulator stack of the gun. A schematic of the transformer is given in figure 1. We show the two core arrangement of 6:1 step up transformers in the figure. An additional change made since the last report is that the volt-second product of the driver pulse transformer has been increased by approximately 16 %. As previously reported the system is immersed in transformer oil, but is now connected to an electron gun. Base pressures are at present limited to about 10^{-5} Torr but plans are in hand to operate the system at lower pressures. The system is now set-up to include an automatic reset of the ferrite cores and to operate in a command trigger mode. Previous results were limited to self break switch operation. More detail on the experimental set up of the modulator is provided in [1].

The electron beam is generated from a 1.8cm diameter, 1mm thick disk of PZT coated with a front surface 200μm silver grid. Emission from ferroelectrics has been described elsewhere [2], where extensive references to the current literature are presented. Emission from the ferroelectric is initiated by the application of a fast rising pulse generated by krytron switched PFNs coupled to the rear surface of the ferroelectric. The pulser is connected to the ferroelectric by a length of RG178 wound around the transformer core adjacent to the secondary windings. The winding inductively decouples the transmission line from the experimental ground. The impedance is reduced to $\sim$12.5Ω,

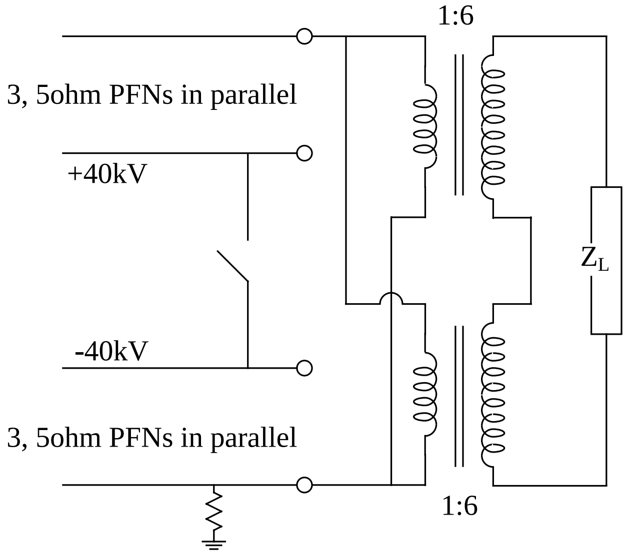

Figure 1: Schematic of pulse transformer.

to provide a fast rise time on the ferroelectric pulse, at the cathode by a 2:1 transformer. In the experiments reported in this paper the tests focussed on determining the emission characteristics of the ferroelectric and not on beam production. This was necessary since no tests of ferroelectric emission have been reported in diodes or electron guns with anode cathode voltages in excess of 50 kV, and the scaling characteristics are required to design the electron gun. The ferroelectric cathode was flush mounted at the center of a 10cm diameter cathode shank. The gridded ferroelectric surface was recessed about 0.3 cm from the front surface of the cathode shank. A confined, but not laminar, electron beam was generated in a converging magnetic field reaching a peak value of up to 3kG about 4cm into a 5cm diameter drift tube. The drift tube was located approximately 6.5cm from the front of the cathode. The beam was collected on a 2.5cm diameter collector about 10cm into the drift tube. EGUN simulations show that the beam will all enter the drift tube and be collected on the center conductor. The beam current is monitored by a Rogowski coil attached to the collector.

3 EXPERIMENTAL DATA

The level of electron emission from the ferroelectric cathode was determined by measuring the current collected on the center conductor in the drift tube. In the absence of a trigger pulse to the rear of the ferroelectric no current was monitored. If the ferroelectric pulse was applied more than 2 μs prior to the diode voltage the beam current remained zero, whereas pulsing the ferroelectric at times $\leq 2.0\mu$s prior to the gun pulse consistently generated an electron current pulse. This result is consistent with previously reported data [3]. Figure 2a shows representative data obtained for the beam current when the delay between the two pulses was about 1.8μs. The current rises to its maximum value in about 200ns and shows a relatively flat top duration of about 250ns. The voltage pulse shown in figure 2b was obtained at 500kV using the two core series winding arrangement feeding a 900Ω resistive load. Note that the 16% increase in the core volume was not in place at the time these records were obtained.

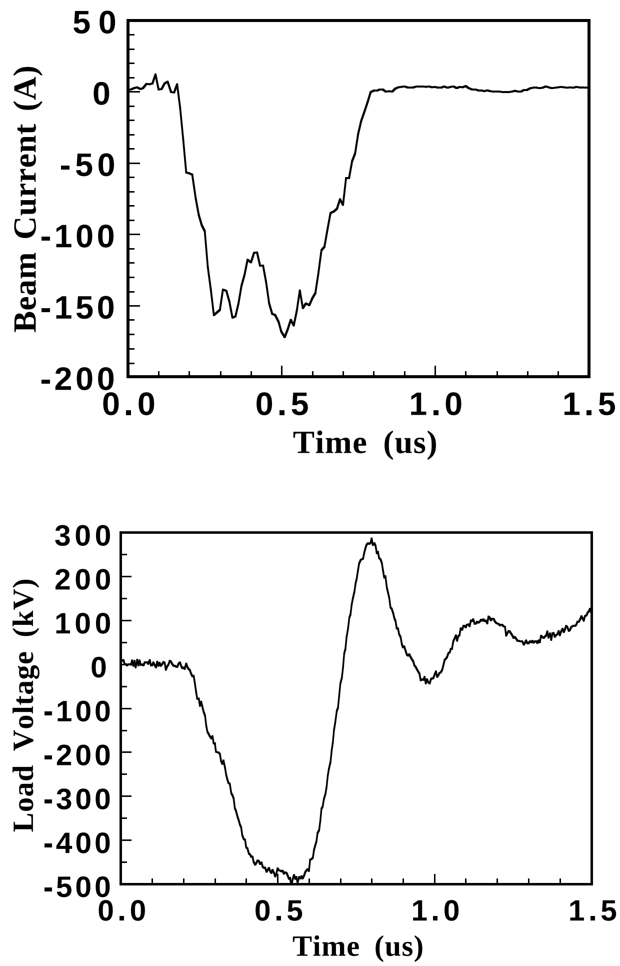

Figure 2: Beam current (100A/div) and the secondary voltage for the 3.3Ω line driven transformer.

In figure 3 we show a plot of the beam current versus the gun voltage to the three halves power. The linear plot indicates a gun perveance of 0.8μperv. Previous lower voltage data show, in vacuum diodes, a current level enhanced by a factor of ~ 100 over that predicted by the Child Langmuir law. At present it is not clear whether the differences are due to the gun voltage or to the long delay (2μs) between the triggering of the ferroelectric and the application of the gun voltage. Our earlier observations at ≤ 50 kV also showed that the diode current dropped to zero with delays in excess of 2μs. In order to achieve the microwave powers desired in the TWT amplifier research program we require at least 200 A beams. This level of emission has been achieved in the present experiments from an exposed 2.8 cm^2 ferroelectric cathode at an average beam current of nearly 75 A/cm^2. Unpublished data, also presented in a companion paper at this meeting, report 20A, emission at

15 kV at a repetition rate of 50 Hz [3]. Although measurements have been made of the emittance of electron beams generated from ferroelectric cathodes no data has been reported under the high voltage, high current conditions achieved in these experiments.

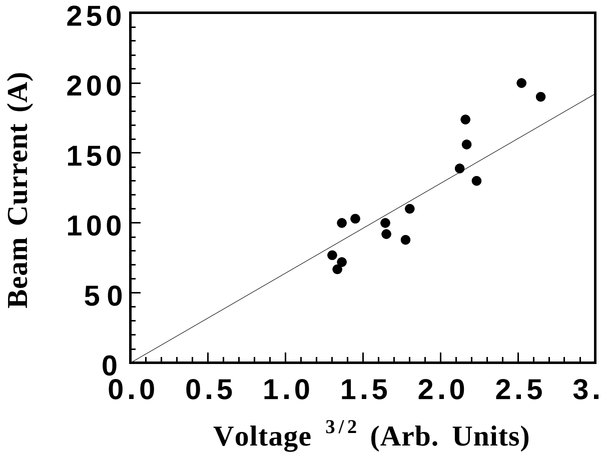

Figure 3: Beam current vs Diode Voltage raised to the three halves power.

4 DISCUSSION OF RESULTS

In the present set of experiments we have reported modifications made to the pulse transformer used to drive the ferroelectric cathode-electron gun. Two configurations have been investigated for the modulator, of these the two 6:1 step up transformers have proved to be the most satisfactory as regards the pulse rise time. The data, on the electron gun emission, were obtained with a single core 12:1 step up transformer.

These electron emission data reported here are the first results on electron beam generation at gun voltages in excess of 50 kV. With the existing delays between the ferroelectric and gun voltage pulses it is not surprising that the beam current was in close accord with that expected on the basis of space charge limited emission, as determined by the EGUN program. The observed currents are consistent with those obtained from EGUN using a 1.8 cm diameter cathode with a gap of about 5-6 cm. The emission is consistent with plasma formation on the front surface of the cathode allowing the high current densities. The current densities obtained are predicted by EGUN with gaps of about 5 cm and are consistent with gap closure velocities of order 2 cm/μs, typical of the figure found in pulse power driven field emission diodes. Previous work has indicated that the emission from a ferroelectric cathode is controlled by the ferroelectric for times of up to about 1 μs after pulsing of the ferroelectric and that plasma effects may dominate at later times. Work is presently in progress studying the emission under conditions where the delay time between the ferroelectric pulse and the diode voltage is reduced below $\sim$1μs.

5 CONCLUSIONS

We have demonstrated operation of a 500kV, 1000Ω electron beam generator capable of delivering a 250ns pulse duration at a low repetition rate. The system will be used to generate 200-500A beams for use in our new 35 GHz source research program. The extension to 500A beam currents may require a larger active emission area. EGUN simulations have been made indicating a suitable gun configuration, which has not yet been tested.

Work is in progress testing the ferroelectric emission process with shorter time delays than the 1.8 μs used in these experiments. The work reported here and in the companion paper (ref 3) at this conference are believed to be the first demonstrations of:

a. ferroelectric cathode emission in MW power level electron guns,

b. ferroelectric cathode operation at 50 Hz repetition rates with current levels of order 20A.

6 REFERENCES

[1] *Design and Operation of a 700kV, 500A Modulator*, J. D. Ivers, G. S. Kerslick, J. A. Nation and L. Schächter, *Proceedings of the 1995 Particle Accelerator Conference*, Dallas, Texas, May 1-5, 1995, vol.2 p1219.

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