

NEW RESULTS ON ELECTRON EMISSION FROM PZT FERROELECTRIC CATHODES*

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Abstract

Ferroelectric cathodes may offer a source of high current density electron beams for applications where the use of conventional cathodes is limited by the required current density, cathode poisoning, or lifetime. In a ferroelectric cathode, electrons are emitted when the spontaneous polarization is rapidly changed by a pulsed electric field applied across the ferroelectric. When no additional voltage is applied to a planar diode gap, emission current densities are on the order of $\sim 1 A/cm^2$. When an additional field is applied to the gap, we have measured current densities of up to $100 A/cm^2$. In this paper we report on two topics: (1) beam extraction into a drift tube at low (10-20kV) voltage and, (2) electron emission, transverse to an applied magnetic field, from a cylindrical ferroelectric cathode. In the former case we report on emission of a 20A beam current in a 300ns pulse repetitively pulsed at rates up to a power supply limited $\sim 50Hz$. The cathode is located in the fringing region of a 3kG solenoid magnetic field. In the second case we find, at low applied gap voltages, that the magnetic field required to suppress the radial current flow is considerably in excess of that predicted for the applied electric field.

1 INTRODUCTION

The study of electron emission from ferroelectrics has advanced through the last several years to the point that we can now consider them for use in electron guns. Among the possible advantages of such emitters is their insensitivity to poisoning, and the possibility of obtaining much larger emission current densities than can normally be obtained from a thermionic cathode. In order to proceed beyond this point requires, (i) a measurement of the emission characteristics at the high applied voltages normally used in electron guns and, (ii) a demonstration of their viability at high repetition rates and, (iii) measurements on the life of ferroelectric cathodes. We have carried out and report in this, and a companion paper [1], an investigation of the first two of the above features. The repetition rate measurements were made at 15kV in an arrangement in which the electrons emitted from an appropriately pulsed 1.8cm diameter ferroelectric disk are injected into a 5cm diameter drift tube located 2.8cm from the surface of the cathode. The flow is focussed by a converging magnetic field into a 1 cm diameter channel. The anode cathode voltage was provided by a 300ns pulse transformer operated at repetition rates of up to 50Hz. The emitted current was found to

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be stable and equal to 20A.

In the high voltage gun experiment peak currents of 200A have been obtained with the cathode-drift tube gap about 6.5cm and the cathode voltage in the 400-500kV range.

In addition to the above measurements we have recently initiated a new experiment designed to help elucidate the electron emission mechanism(s) further, and also to provide a possible new means of generating an annular electron beam. In this experiment a 2.5cm long, 2.5cm diameter PZT sample is mounted in a coaxial diode assembly with an anode cathode separation of 1cm. An axial applied magnetic field is used to determine the cut-off condition for radial current flow. As the radial current decreases with increasing applied magnetic field an axial current flow develops with the flow in an annular channel of radius approximately equal to that of the ferroelectric cylinder.

The detailed experimental results and their implications are discussed in the following sections.

2 EXPERIMENTAL DATA

The essential features of the gun system are shown schematically in figure 1, where the ferroelectric cathode is located in the fringing field of a solenoid field coil system. Note that this arrangement does not produce a constant radius beam as it propagates through the system. The flow is indeed sharply focussed at certain axial locations; it is however a confined flow which does not intercept the tube walls.

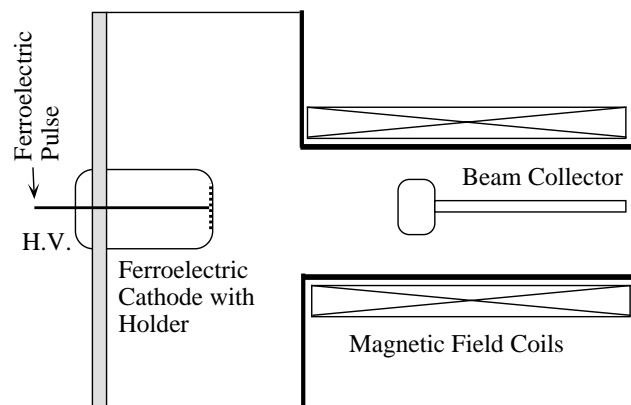


Figure 1: Schematic of 15kV ferroelectric gun experiment.

We show in figure 2 experimental data for the beam current in the 15kV gun experiment. The beam current is an overlay of 46 consecutive events at a power supply limited 47Hz.

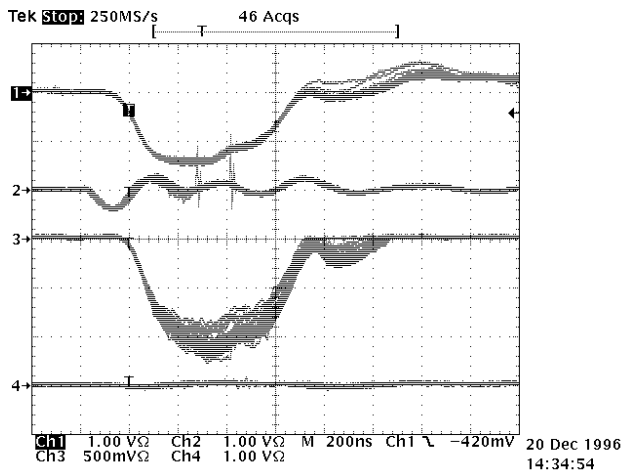


Figure 2: Ferroelectric cathode emission at $\sim 50\text{Hz}$. Ch1: V_{gap} , 12kV/div; Ch2: I_{ferro} , 70A/div; Ch3: I_{anode} , 10A/div.

In figure 3 we show a schematic of the radial diode assembly with data obtained at applied voltages of 1.75 and 40kV in figure 4. In figure 4 the radial and axial current flows are shown as a function of the strength of the axial magnetic field. The critical field, required to suppress single particle radial current flow, is indicated on the figures. The 40kV data were obtained using a pulse line feeding a 3:1 step up transformer. The pulse line has an output impedance of 300Ω and generates a 300ns duration pulse which is triggered separately, and subsequently to the ferroelectric. A 500Ω resistor is placed in parallel with the vacuum diode. This limits the voltage excursion if the ferroelectric fails to emit. Typically delays between the two pulses are $\sim 600 \pm 300\text{ns}$.

We show in figure 5 typical data from the radial and axial current monitors at 40kV for low $\sim 0.07\text{T}$ and high $\sim 0.2\text{T}$ axial magnetic fields. As the magnetic field is increased the radial current drops to a value close to zero while, as expected, the axial current increases. Peak axial currents of about 250A have been monitored.

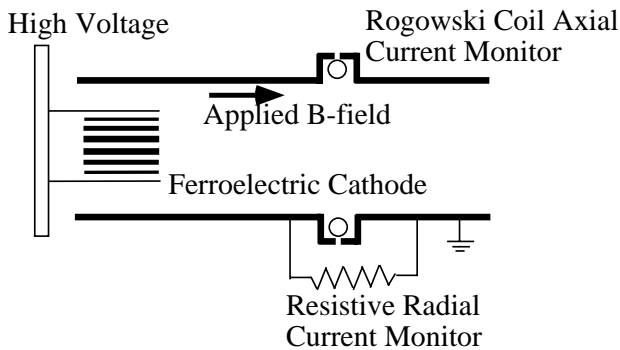


Figure 3: Schematic of cylindrical ferroelectric cathode experiment.

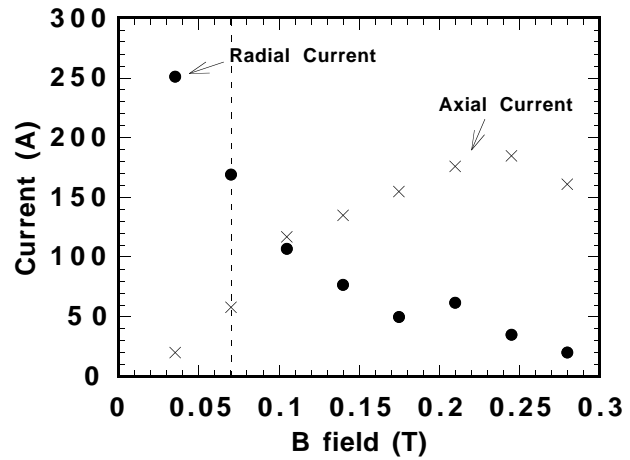
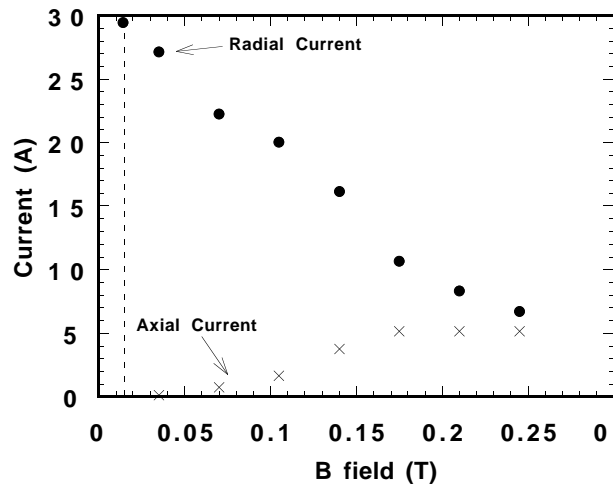


Figure 4: Axial and radial current as a function of applied B field for two applied voltages: 1.75kV (upper frame) and 40kV (lower frame). The critical B field in each case is indicated by the vertical dashed line.

3 DISCUSSION OF RESULTS

50Hz Repetition Rate Data: The data presented gives an encouraging view of the potential of ferroelectric cathodes for use in high repetition rate experiments. It is worth noting that the current is limited in these experiments by the potential depression in the drift space. A further feature is the effect of conditioning on the beam current. These experiments were carried out in relatively poor vacuum 10^{-5} Torr and the emission repeatability improved dramatically with time. Arcing at the anode surface could be inferred from current flow from the anode to the cathode. This process was rapidly reduced to a very low probability with operation at even modest repetition rates. The data presented were obtained after a few thousand shots had been obtained with the assembly.

Electron current in radial diode geometries: The experiment to measure the emission transverse to an applied axial magnetic field was designed to show the potential of the ferroelectric as a source for production of an annular

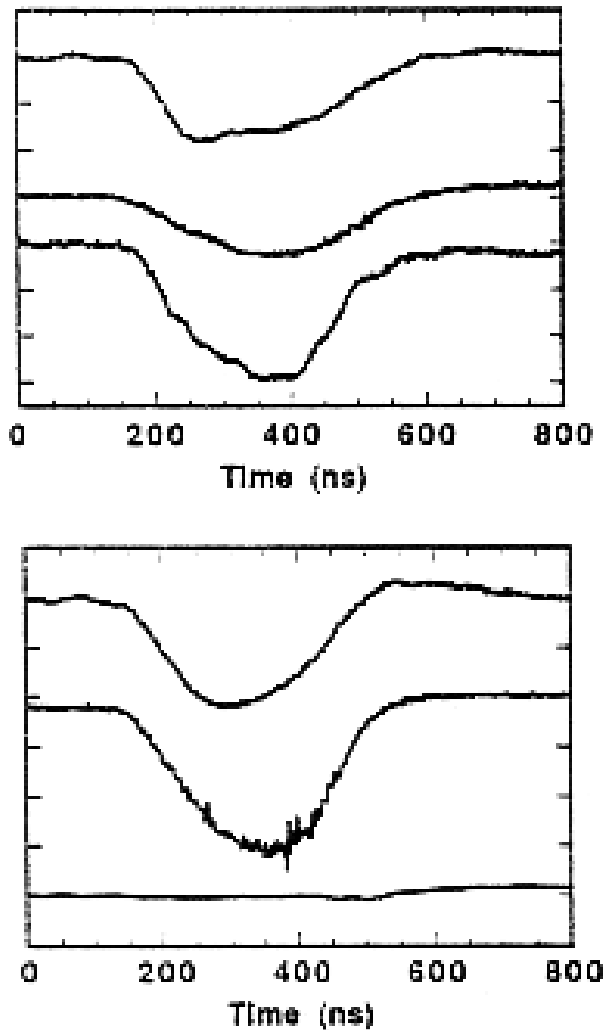


Figure 5: Radial and axial currents emitted from cylindrical ferroelectric for $B=0.07T$ (upper frame) and $B=0.2T$ (lower frame). Top waveform: V_{diode} , 25kV/div; Middle waveform: I_{axial} , 100A/div; Bottom waveform: I_{radial} , 80A/div.

electron beam and further to help clarify the emission process from the ferroelectric diode. Three mechanisms have been proposed to account for the observed emission current densities [3]. The first entails the emission of electrons with an initial velocity, the second the formation of a deep potential well resulting from the field enhanced ejection of the electrons, and the third plasma formation and subsequent anode-cathode gap closure. As regards these mechanisms we have never detected electrons with initial energies exceeding $\sim 600V$. This initial energy is insufficient to account for the observed current flow in our experiments. Based on the radial current flow at magnetic fields strengths well in excess of the critical field for magnetic insulation, the low voltage ($\sim 2kV$) data shown in figure 4 would imply a potential well depth of order 80kV. The more rapid fall off of the radial current close to the critical field at high applied potentials is consistent with this observation. The third mechanism is based on the concept

of an ambi-polar like motion across the anode cathode gap. Based on the measured injection electron energies a limited number of protons could achieve velocities of about $10\text{ cm}/\mu\text{s}$ (higher atomic number ions would give lower velocities). Gap closure, albeit with low plasma density, could then occur in the 1 cm radial gap in times of order 100ns. At the high voltages ($\sim 30 - 60kV$) used in these experiments the sense and magnitude of the applied electric field would tend to result in the ion motion being suppressed close to the anode and negate this process. The observation of reverse diode current flow at late times ($\geq 0.6\mu\text{s}$) indicates that the diode eventually fills with plasma. Based on these observations we conclude that the deep potential well is probably the dominant mechanism at early time and that plasma controlled flow dominates at later times. We note, from events in which the ferroelectric is switched during the main anode cathode voltage pulse, that axial current flow dominates at high magnetic fields and follows the applied voltage pulse with zero delay, following the start of the ferroelectric switching current. The radial current flow is much smaller than the axial flow in these conditions and does not start typically until there has been a sufficiently large change from the remnant polarization of the medium. This is consistent with the time taken to form a deep potential well.

4 CONCLUSIONS

The observations reported in this paper show that electron beams can be produced from ferroelectric cathodes, at interesting current levels for high power microwave generation. The production of 200-300A beams in both radial and axial emission configurations at current densities of order $75A/cm^2$ has been achieved. The data obtained in the radial flow configuration experiment sheds additional light on the emission mechanisms from ferroelectrics. This work is continuing.

5 REFERENCES

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