ELECTRON EMISSION FROM FERROELECTRIC CERAMICS

J. D. Ivers, R. Advani, J. A. Nation, and L. Schachter
Laboratory of Plasma Studies and School of Electrical Engineering
Cornell University, Ithaca, N.Y. 14853

Abstract.

We report the results of experiments on the emission of electrons from ferroelectrics. A sample of PZT is pulsed to reverse the direction of the spontaneous polarization within the material. This releases the surface charge accumulated on the ferroelectric which is needed to reduce the external electric field to a low value. Surface charge densities may amount to about 0.5 C/m^2. In these experiments the emitted electron current density reaches a peak value of up to 70 A/cm^2 for a diode gap of 4 mm and an extraction voltage of 500 V. Beam current densities exceed the Child Langmuir law for space charge limited emission by factors of up to 400. We present measurements showing the dependence of the emission on the diode voltage and spacing. A discussion is presented summarizing our present understanding of the emission process and its limitations.

I. INTRODUCTION

Recent experiments at CERN[1-3] and at the Lebedev Institute[4] have demonstrated that it is possible to extract high current density electron beams from ferroelectrics. The emitted beams may have very desireable characteristics, such as low emittance, for both low and high current accelerator applications. The emission comes from electrons on the surface of the polarized ferroelectric which serve to screen the polarization charge from the exterior of the material. Charge densities of more than 10^{14} electrons per square centimeter are typical for these materials. The use of ferroelectrics for switching has also been proposed by Riege.

We have recently initiated a program to investigate the emission processes and to document their characteristics. In this paper we present our first results in this program, namely an investigtion of the I-V characteristics of a diode using a ferroelectric cathode. We also report on certain features of the emission associated with the piezoelectric properties of ferroelectric materials.

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is shown schematically in fig. 1. A 1mm thick, 2.5 cm diameter ferroelectric disk is mounted as the load on a 10 Ohm characteristic impedance transmission line. The effective emission area is 1 cm^2. The line is switched by a krytron applying a 200nsec, 1kV pulse to the sample. The sample is oriented with the polarization vector pointing into the diode so that the screening is accomplished by electrons. A positive pulse is applied to the rear face of the ferroelectric and the emission surface is held at ground potential. For these experiments we used LTZ-2 (Transducer Products) as the ferroelectric source. The highly capacitive ferroelectric load is shunted by a 22 Ohm resistor to improve the pulse shape. The cathode is coated with a thin (1 micron) silver coating on its rear surface and a gridded emission surface with alternate silver coated and uncoated strips of 200 micron width on its front surface. The silver coating is needed in order to apply the switching pulse to reverse the spontaneous polarization in the material and hence release the electrons into the diode gap. A planar carbon anode is located either 4 or 10 mm from the emission surface. The anode is maintained at a positive potential with respect to the cathode by a charged transmission line. Current flow through the diode discharges the line. We record the line current at the diode and either directly monitor the gap voltage or determine it from a knowledge of the current and the transmission line impedance. Lines with characteristic impedances ranging from 12.5 to 50 Ohms have been used as the load. The diode is maintained at a base pressure of 10^{-5} Torr. There is no need for high vacuum since the cathode is not susceptible to poisoning.

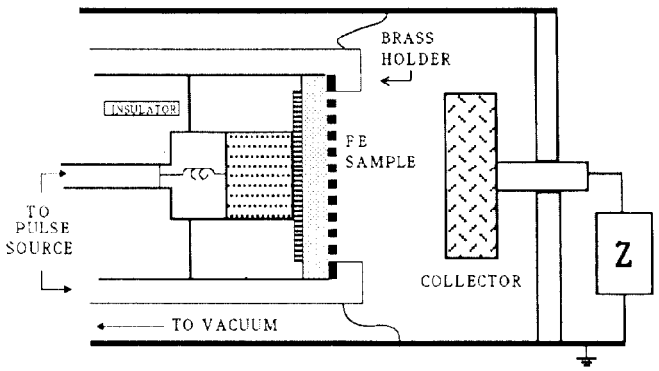

Fig. 1. Experimental arrangement used for the study of electron emission from a ferroelectric cathode.

III. EXPERIMENTAL RESULTS.

Fig 2. shows three oscilloscope traces obtained for the diode current with a 4mm gap and a 50 Ohm load. The transmission line load was initially charged to 100, 300, and 500 V for the three data events. The beam current length was set by the length of the cable and does not reflect charge emission limitations. The steady nature of the current is typical of this data although for order of magnitude greater current density emission the current increases in time during the first half of the pulse. Similar data have been obtained for

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other gaps of up to a 10mm. In fig. 3 we plot the diode current versus the gap voltage for the 4 and 10 mm gaps.

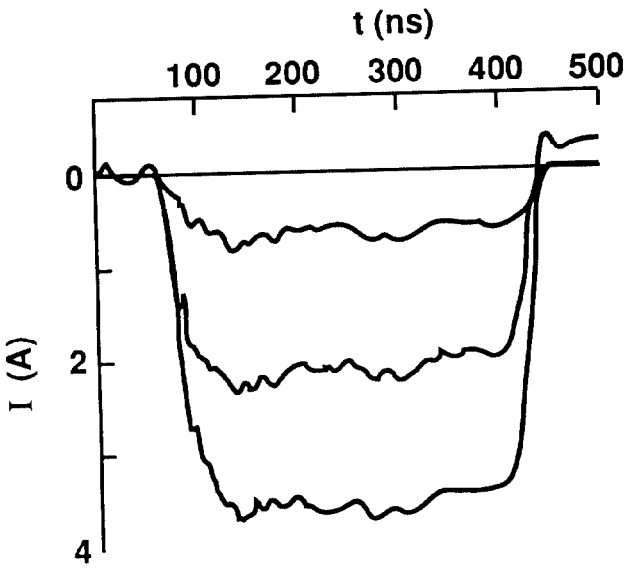

Fig 2. Diode current as a function of time for 100, 300 and 500 Volt initial charge on the 50 Ohm impedance line.

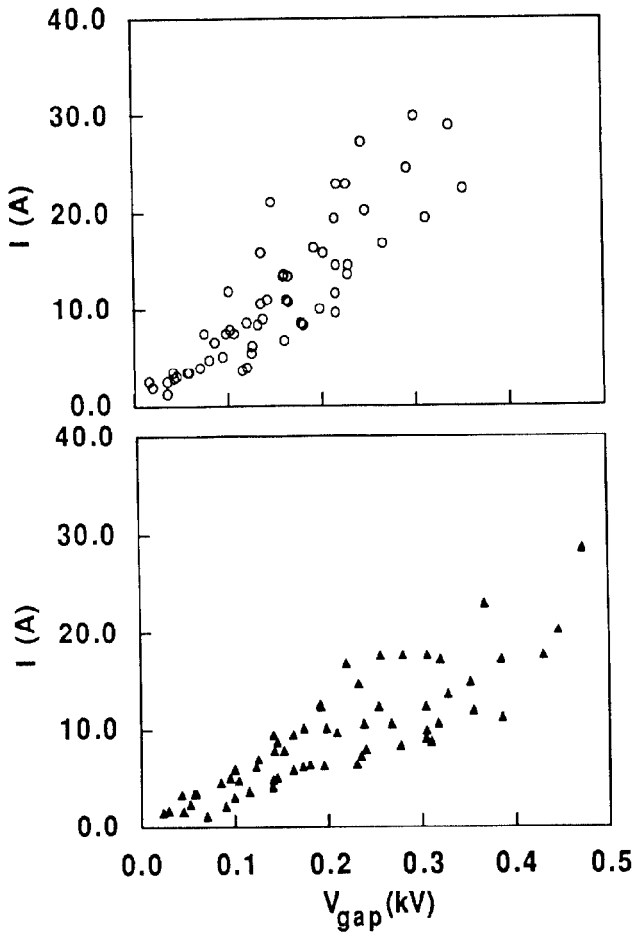

Fig 3. Diode I-V characteristics for a 4 mm (upper plot) and 10 mm (lower plot) anode -cathode separation.

The results indicate an almost linear scaling of the beam current with the diode voltage, although there is evidence of some curvature in the 4mm plot. At present there is insufficent data to obtain a scaling law with the diode gap. The details of the scaling are somewhat obscured by the spread in the data obtained, especially at the higher currents.

In the data presented above we have applied a pulse to the cathode in such a sense as to reduce the remnant polarization to zero. Emission is also found when the polarity of the switching pulse is reversed. The temporal characteristics of the emission are shown in fig 4. Even in

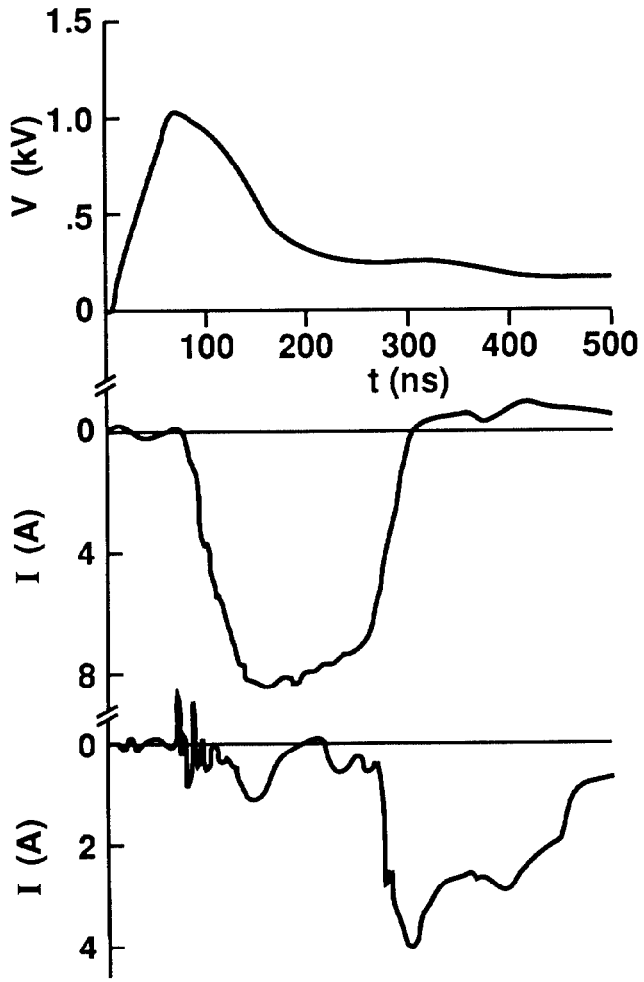

Fig 4. Emission characteristics of a ferroelectric cathode as a function of the polarity of the switching pulse. The upper trace shows the switching pulse and the lower two traces the beam current for the usual switching polarity (middle trace) and the emission with a reverse polarity (lower trace) pulse.

normal switching case we observe a delay of between 50 and 100 nsec between the start of the pulse and the electron emission. In the reverse polarity weak emission occurs after a comparable delay and is followed by a stronger emission 200 nsec. later. The delay corresponds to the half period of the natural oscillation of the ferroelectric sample. This

phenomenon has also been observed with a charged capacitor as the diode load, with up to three equally spaced electron emission pulses in the 2 microsecond sweep monitored. The ferroelectric ceramics are also piezoelectric and change in length when a voltage is applied to the poled sample. In our experiments the sample cannot adjust its size in the time scale of the applied electric field pulse and the emission delay reflects the time taken for the material to respond to the applied impulse. Following the release of the switching pulse the ferroelectric oscillates at a characteristic frequency which is determined by the sample material and its thickness. The electron emission pulses occur once every cycle of the natural oscillation.

IV. DISCUSSION OF RESULTS.

The qualitative picture of the emission process is clear. A detailed understanding of the emission, however, still requires further study. Among the features of the emission process, which differ from other methods of electron generation is due to the screening electrons being injected into the diode gap as the polarization is reversed. Note that the impulse applied to the electrons is probable quite small since the system, consisting of the ferroelectric sample and the diode will retain macroscopic charge neutrality. There is however a net dipole force which pushes the electrons into the gap. The grid electrodes tend to screen this force out of the gap region for distances greater than the separation of the grid elements i.e. 200 micron. Qualitatively we expect to find more than 10^{14} electrons/cm^2 injected into the gap as the polarization is reversed. The majority of these electrons may lie close to the cathode since the I-V characteristic does not depend strongly on the gap spacing. As a result of the injection of the electrons into the gap the current densities achieved are much greater than those calculated using the Child Langmuir law. For example a current of 30 A in a 4mm gap with a 300V diode voltage exceeds the Child Langmuir current by a factor of 400.

Note that the screening effect occurs essentially instantaneously at the plated surfaces since this is controlled by the ε/σ time constant of the silver plating. The corresponding time interval for the ferroelectric is, at room temperature, of order of a thousand seconds and it is not clear that the charge can readjust rapidly except by surface discharges or by breakdown in the ferroelectric itself. The multiple pulses observed in the emission suggest that the readjustment occurs on a time scale of order of a microsecond. Other experiments on low repetition rate operation show some evidence of a reduced emission current density when the repetition rate exceeds about 1 Hz.

The work by Riege indicates the existence of electrons emitted with energies up to that corresponding to the voltage of the ferroelectric pulser. Our data shows that the diode current is zero at a gap voltage of zero. We have also used a grid between the cathode and the anode and searched for higher energy electrons than could be accounted for by the gap potential. No such electrons have been detected to date in our experiments.

The pulse duration of the electron emission has been controlled in our experiments by the length of the pulse line used. We have expended the pulse duration to more than 1 microsecond, and with capacitive loads have recorded sub 100nsec pulse durations. The limit appears to be in the total charge available

To date we have not attempted to use ferroelectric emission in conjunction with microwave circuits but it would appear that they might be well suited to applications where modulated beams or even single picosecond pulses are required. In these cases the emission would be immediately followed by injection into a cavity for modulation of the beam while the energy is still small. We also plan to carry out experiments to measure the emittance of the beams produced.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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